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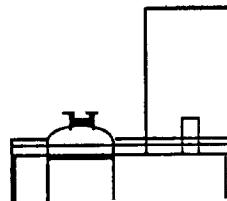
NAS8-37666

VOLUME II

October 1990

**Appendix G
Tank Pressurization
Control System Study,
Honeywell Space and
Strategic Operations**

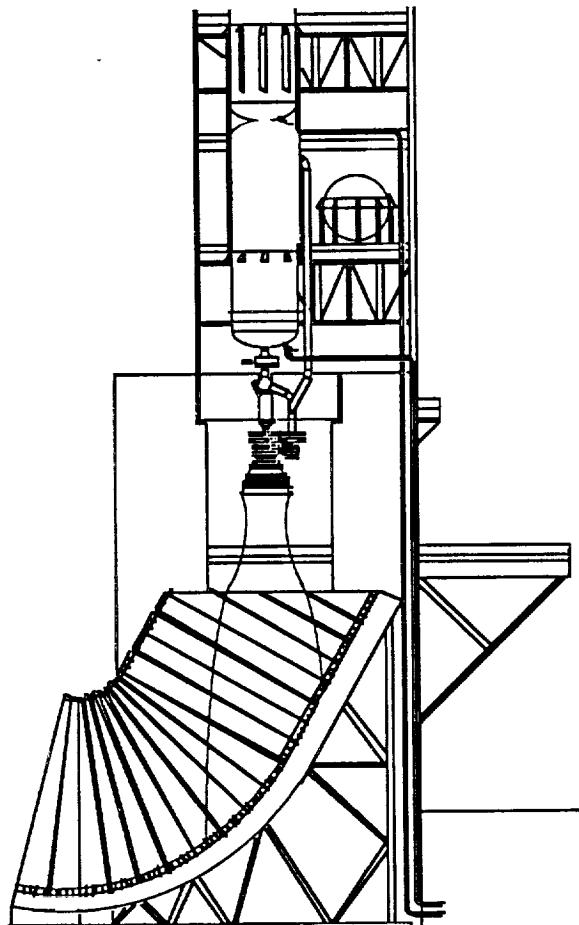
**Propellant Tank
Pressurization System
Technology Program**



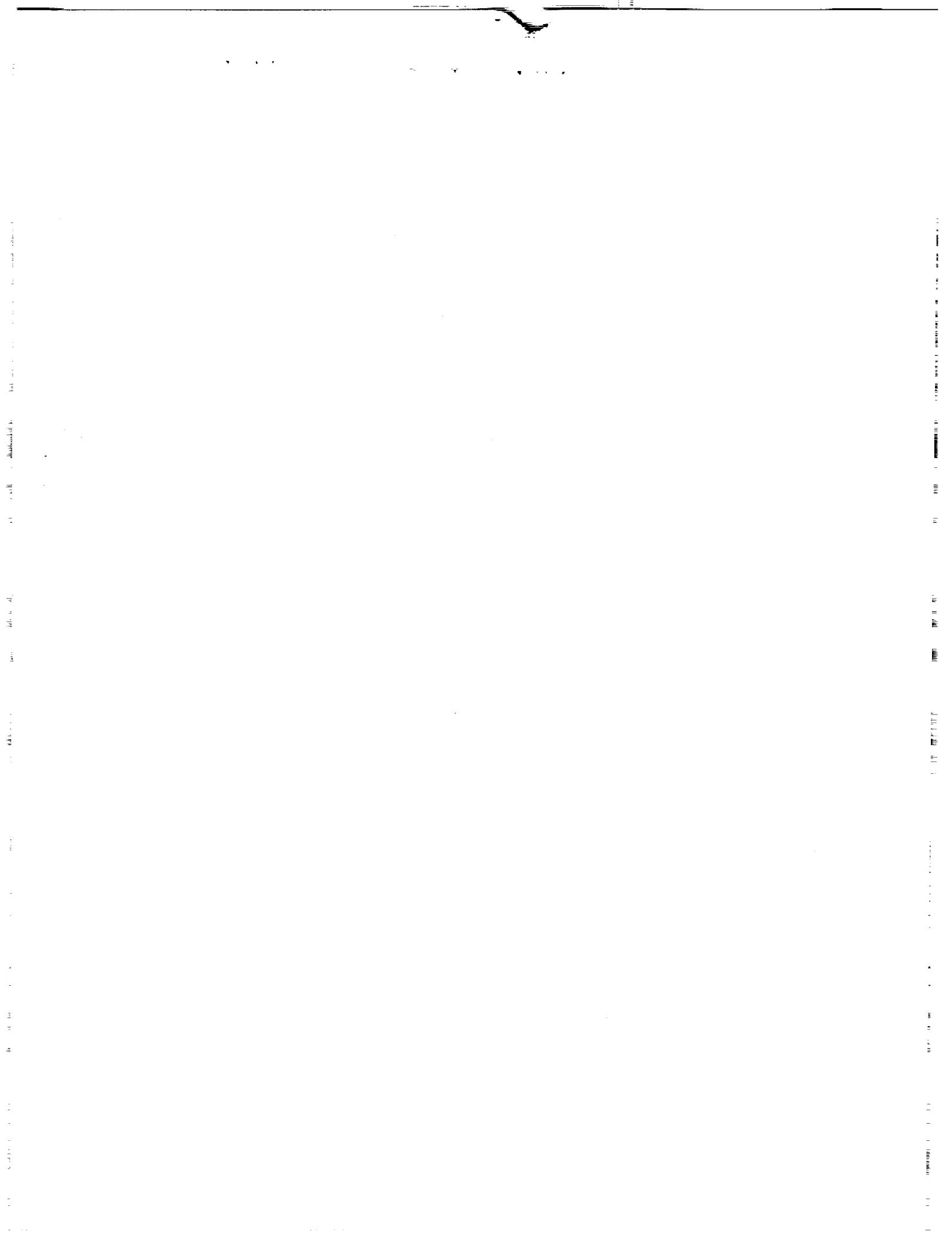
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(NASA-CR-184152) PROPELLANT TANK
PRESSURIZATION SYSTEM TECHNOLOGY PROGRAM.
VOLUME 2, APPENDIX G: TANK PRESSURIZATION
CONTROL SYSTEM STUDY (Martin Marietta
Corp.) 311 p

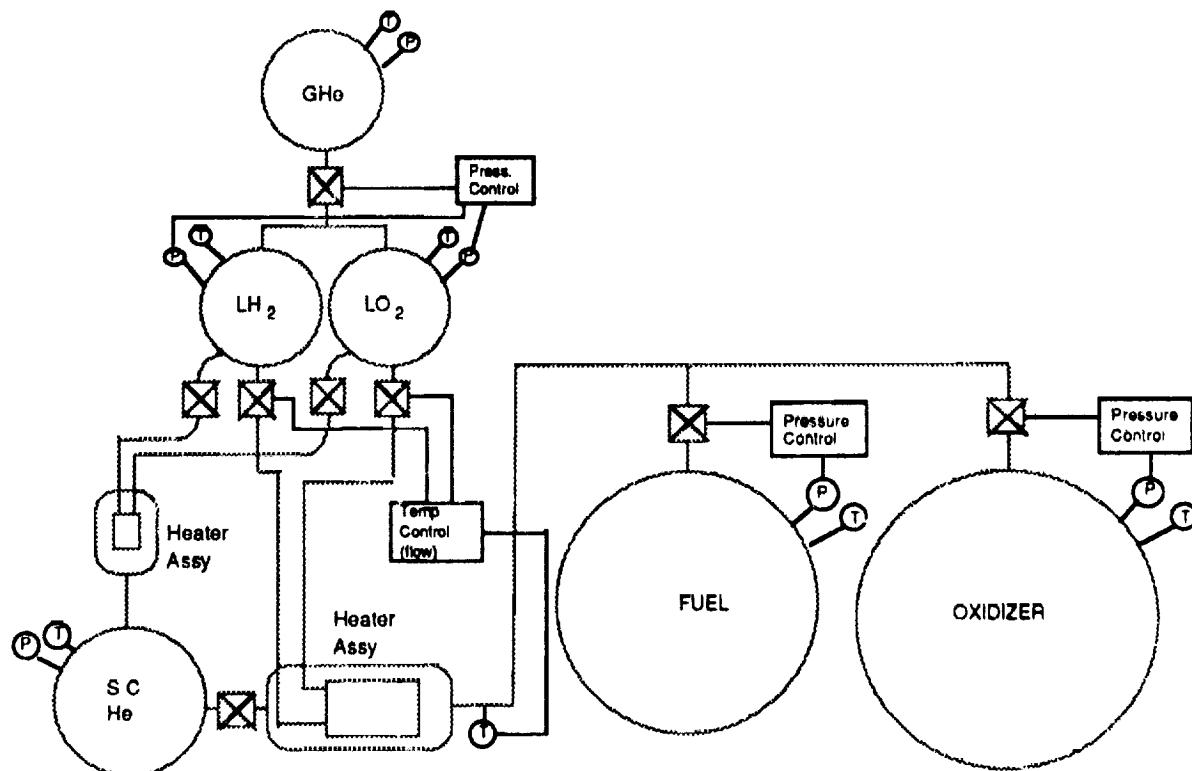
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MARTIN MARIETTA
MANNED SPACE SYSTEMS



PROPELLANT TANK PRESSURIZATION TECHNOLOGY PROGRAM



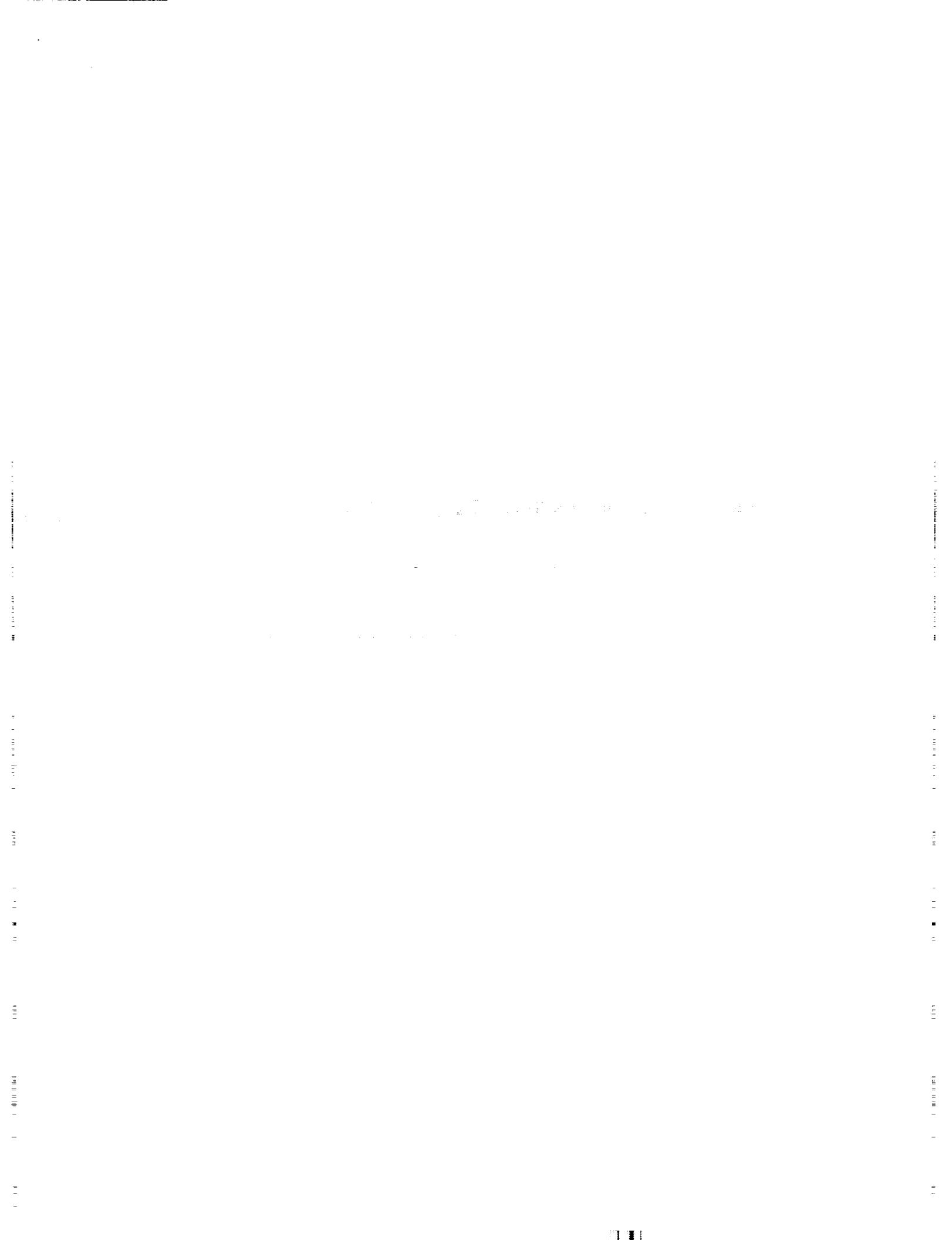
TANK PRESSURIZATION CONTROL SYSTEM STUDY

Honeywell
Space and Strategic Operations
Clearwater, Florida

**CONTROL SYSTEM FOR THE PROPELLANT TANK
PRESSURIZATION TECHNOLOGY PROGRAM**

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PROPELLANT TANK PRESSURIZATION TECHNOLOGY PROGRAM
Tank Pressurization Control System Study

OBJECTIVES

- Define the requirements for the flight tank pressurization control system.
- Establish control system discriminators between candidate tank pressurization system configurations.
- Design, model, and analyze control systems for selected flight pressurization system configurations.
- Estimate cost of a redundant control system for a selected flight tank pressurization system configuration.

PROPELLANT TANK PRESSURIZATION TECHNOLOGY PROGRAM
Tank Pressurization Control System Study

TASK I - Tank Pressurization System Configuration Trade Study.

Develop tank pressurization control system scoring criteria and rationale. Rank tank pressurization system configurations according to that criteria.

TASK II - Evaluate Tank Pressurization Control System Performance.

Develop, implement computer simulations, and analyze coarse models of three selected tank pressurization system configurations.

TASK III - ROM Cost Estimate of Pressurization Control System.

Prepare ROM cost estimate for optimized, preferred candidate including redundancy

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PROPELLANT TANK PRESSURIZATION TECHNOLOGY PROGRAM
Tank Pressurization Control System Study

TASK I - Tank Pressurization System Configuration Trade Study.

PHASE I

- Derive requirements for flight pressurization control system.
- Establish control system trade study scoring criteria and provide rationale.
- Define coarse control configuration for each of 9 initial pressurization system configurations.
- Apply weighted scoring criteria to candidate control systems and rank them.

PROPELLANT TANK PRESSURIZATION TECHNOLOGY PROGRAM
Tank Pressurization Control System Study

TASK I - Tank Pressurization System Configuration Trade Study.

PHASE II

- Define coarse control requirements for new pressurization concepts and refined Phase I configurations.
- Apply weighted scoring criteria to the six Phase II configurations.
- Supply control system ranking as input to select 3 candidates for further evaluation.

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PROPELLANT TANK PRESSURIZATION TECHNOLOGY PROGRAM
Tank Pressurization Control System Study

TASK II - Evaluate Tank Pressurization Control System Performance.

MODEL BUILD AND ANALYSIS

- Develop coarse analytic models of the three flight tank pressurization system configurations including control systems selected in TASK I, Phase II.
- Implement the analytic models into computer based simulations.
- Evaluate control feasibility and complexity of the three configurations and identify control discriminators between the three systems based on analysis of the results of the computer based simulations.
- Use best configuration to evaluate control system robustness for two pressurization system failure scenarios

PROPELANT TANK PRESSURIZATION TECHNOLOGY PROGRAM
Tank Pressurization Control System Study

TASK III - ROM Cost Estimate of Pressurization Control System.

ROM COST ESTIMATE

- Establish redundancy level assumptions
- Prepare detailed ROM cost estimate for best configuration identified in
TASK II.

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PROPELLANT TANK PRESSURIZATION TECHNOLOGY PROGRAM
Configuration Trade Study - Phase I

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REQUIREMENTS

- Oxidizer and fuel tank pressures to be controlled to within ± 5.0 percent
- The primary heat source is used to heat the helium to constant temperature.
- The secondary heat source will be sufficient to maintain pressure in the helium tank high enough to complete the 120 second mission.
- System LO₂ volume flow rate 112.4 ft³/sec.
- System RP-1 volume flow rate 65.9 ft³/sec.
- Initial ullage volume of 5%.
- Maximum LO₂ and RP-1 ullage temperature 800°R
- Maximum He pressurant temperature 1000°R exiting primary heat source.

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FLIGHT PRESSURIZATION SYSTEM-CONTROL SYSTEM SCORING

EVALUATION CRITERIA (SCORE OF 0=BEST, WORST,10=BEST)	ALTERNATIVE CONCEPTS								WEIGHTING (%)
	# 2	# 2 A	# 3	# 4	# 4 A	# 4 B	# 5	# 7 *	
ACTIVE LOOP SCORE	8	10	6	6	8	4	4	8	6
START-UP UNIQUE	10	10	10	10	10	0	10	10	10
CONTROL SIMPLICITY	7	10	9	9	9	7	7	9	40
INSTRUMENTATION SIMPLICITY	7	10	9	10	10	4	7	9	20
SENSORS SCORE	8	8	10	8	8	5	10	8	10
FINAL SCORE (10=BEST)	7.8	9.8	9.0	9.0	9.2	6.5	5.6	9.0	7.6

* - CHECK VALVE IS NEEDED

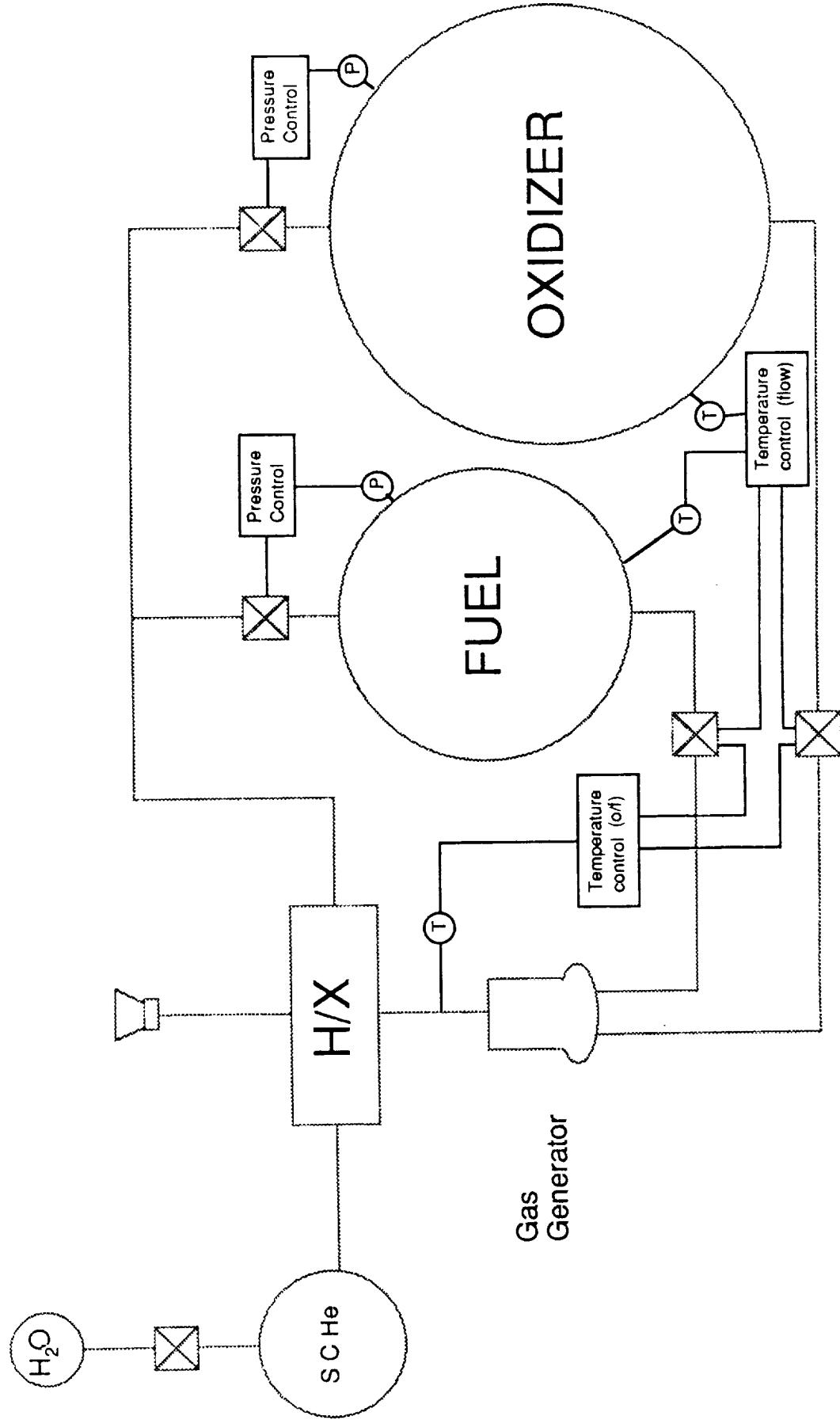
NOTE: THESE ARE THE LATEST UPDATES AS OF 10/13/89.

FLIGHT PRESSURIZATION SYSTEM-CONTROL SYSTEM RATIONALE

EVAL. CRITERIA	ALTERNATIVE CONCEPTS								EXPLANATION
	# 2	# 2A	# 3	# 4	# 4A	# 4B	# 5	# 7 *	
Active loops required	4	3	5	5	4	5	6	4	5
ACTIVE LOOP SCORE	8	10	6	6	8	4	4	8	6
START-UP UNIQUE	10	10	10	10	10	0	0	10	10
CONTROL SIMPLICITY	7,A	10	9	9	7,B	7	9,D	7	7
INSTR. SIMPLICITY	7,A	10	9	10	10	4,C	7	9	7
Sensor sets required	10	10	8	10	10	13	8	10	10
SENSORS SCORE	8	8	10	8	8	5	10	8	8

- A - GAS GENERATOR: HIGH FREQUENCY, HIGH TEMPERATURE MEASUREMENT
- B - TRANSIENT RESPONSE OF CATALYST DIFFICULT TO DETERMINE A TRANSFER FUNCTION
- C - INSTRUMENTATION THRU TANK WALL, DETERMINING HOT SPOT LOCATION IS DIFFICULT
- D - ONLY A CHECK VALVE IS NEEDED.

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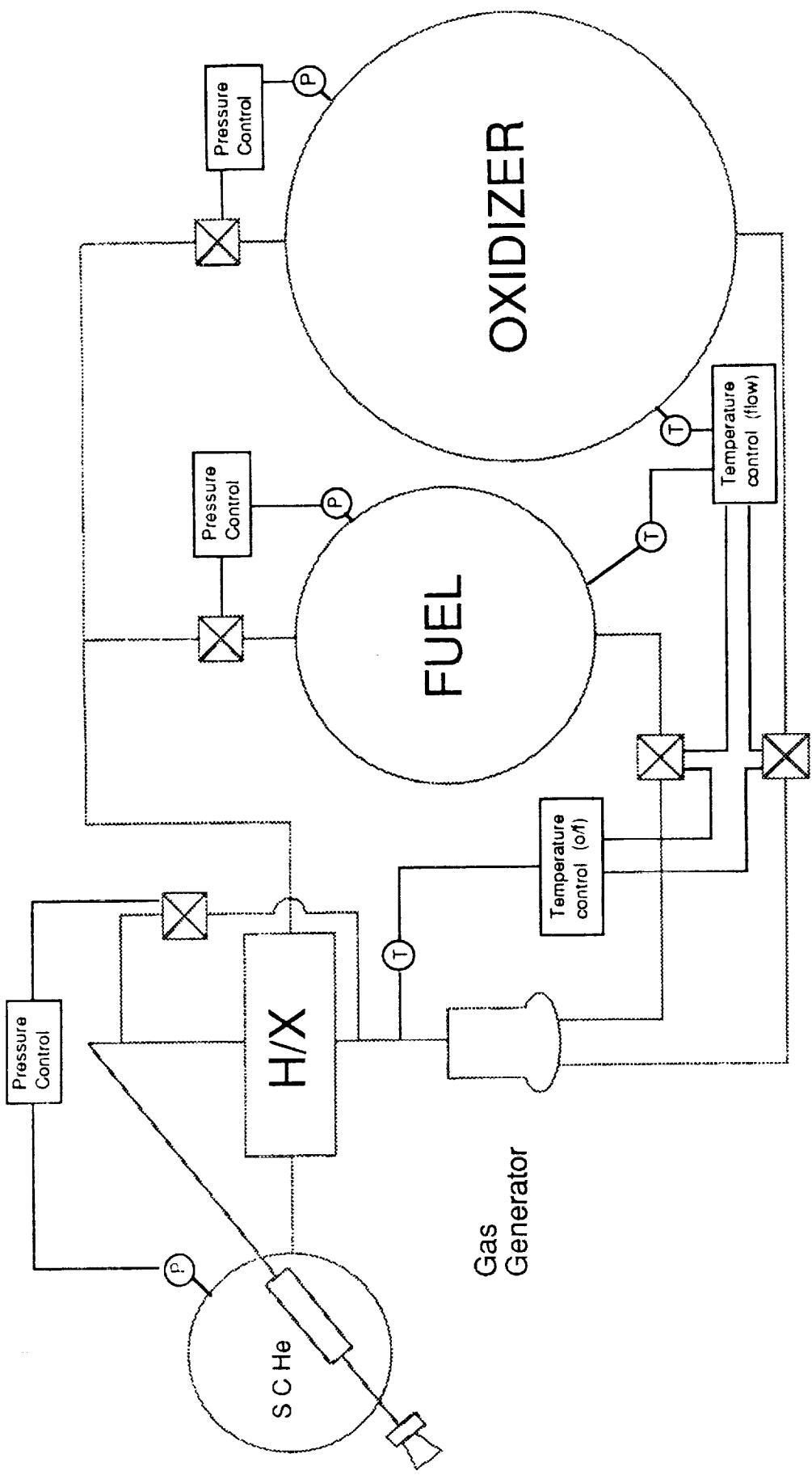


Candidate #2

Honeywell

Steam Expulsion and Gas Generator Heating

11

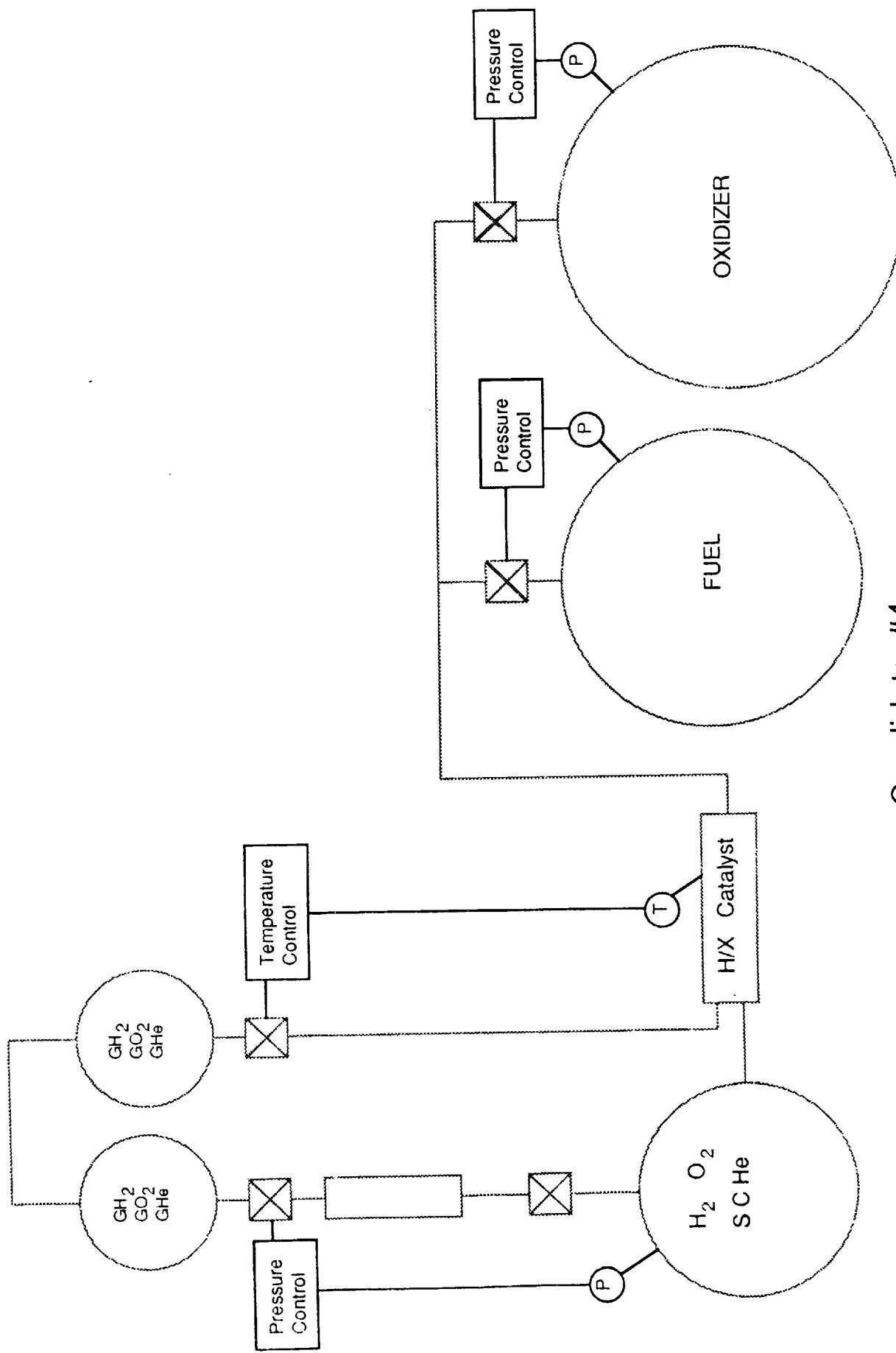


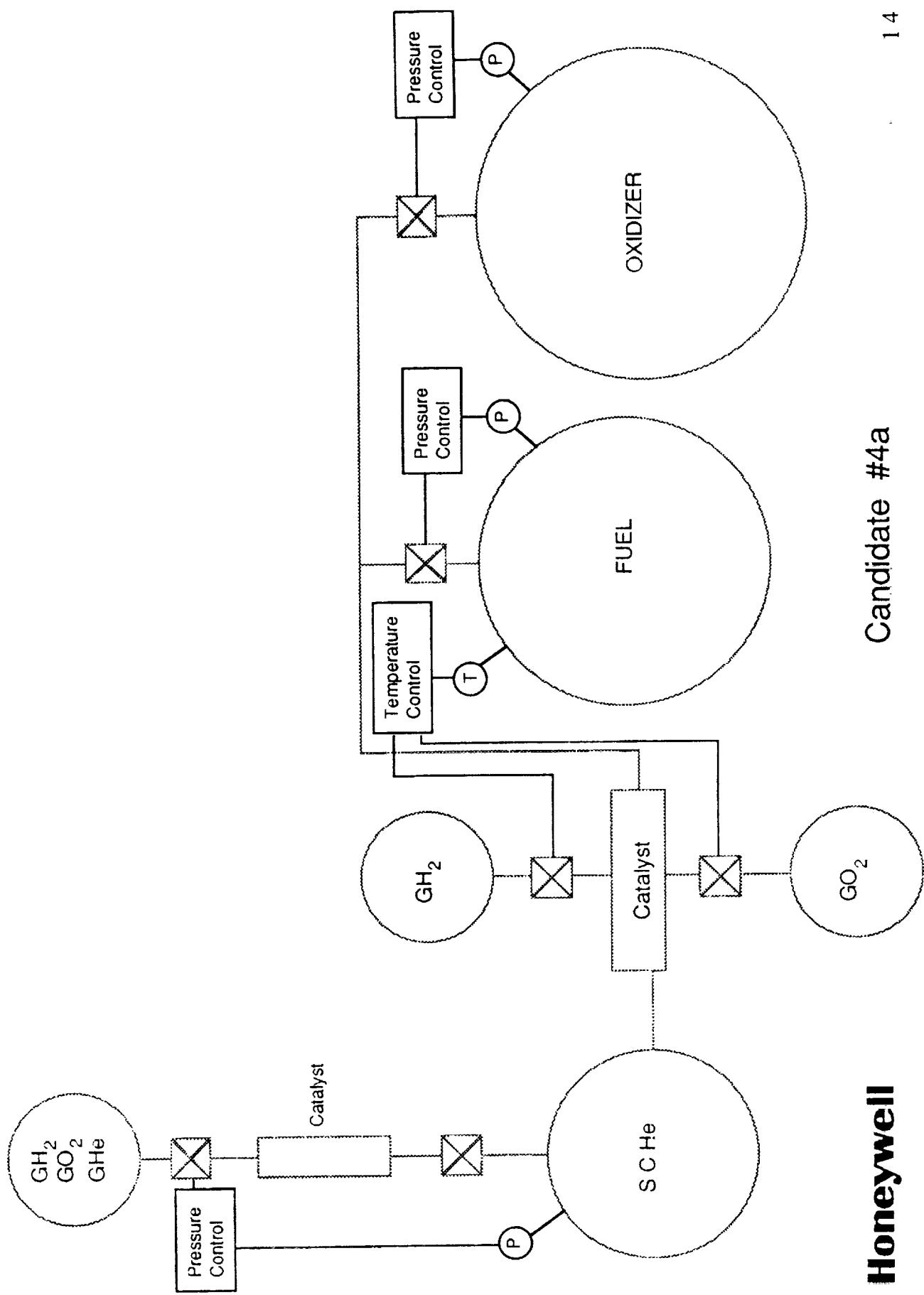
Candidate #3
Gas Generator Used for Primary Heating With Waste Heat He Pressurization

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Candidate #4
 $\text{He}_2, \text{H}_2, \text{O}_2$, Catalyst Bed Energy Source

Honeywell





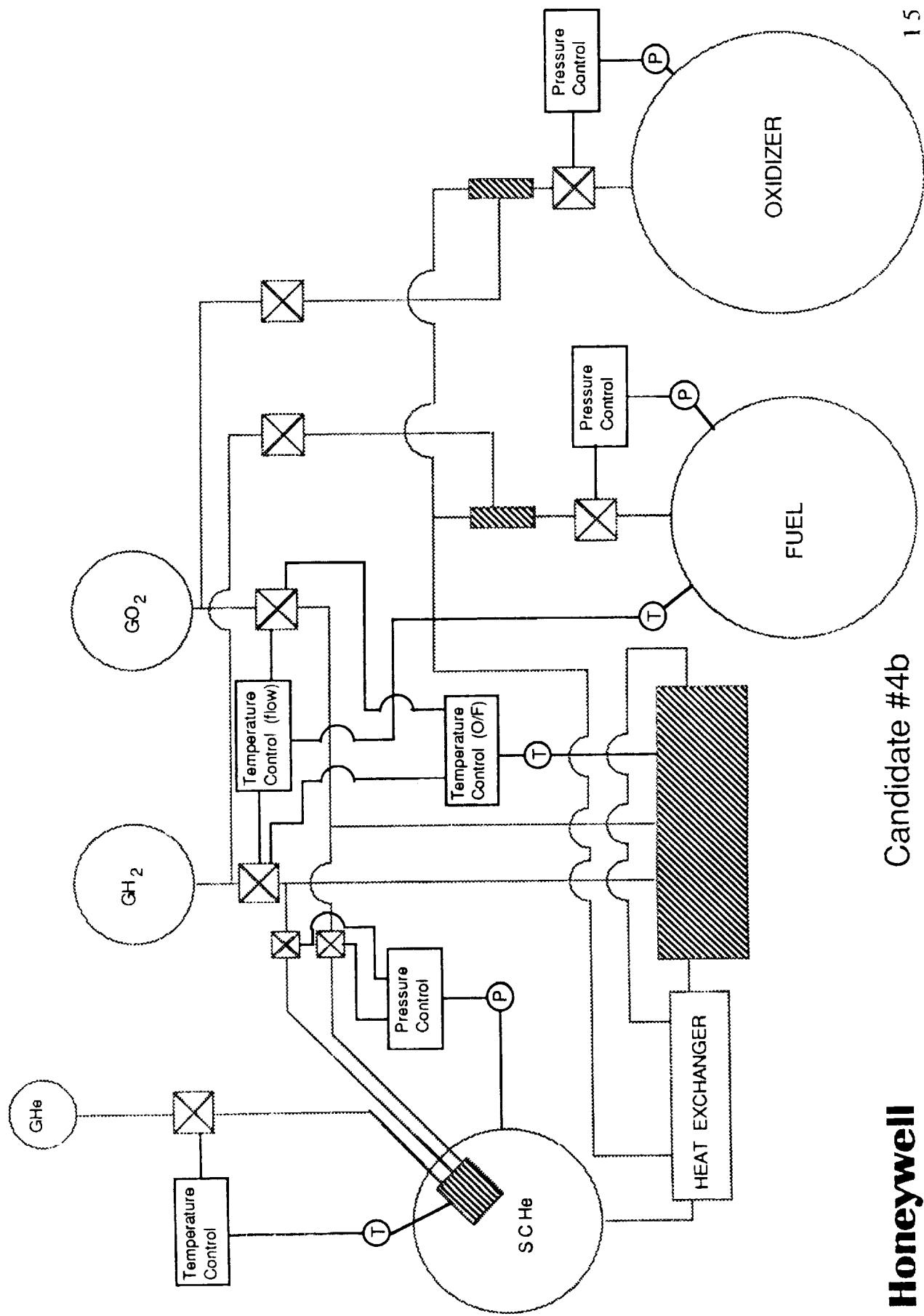
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Candidate #4b

He, O₂, H₂ Catalyst Bed Energy Source

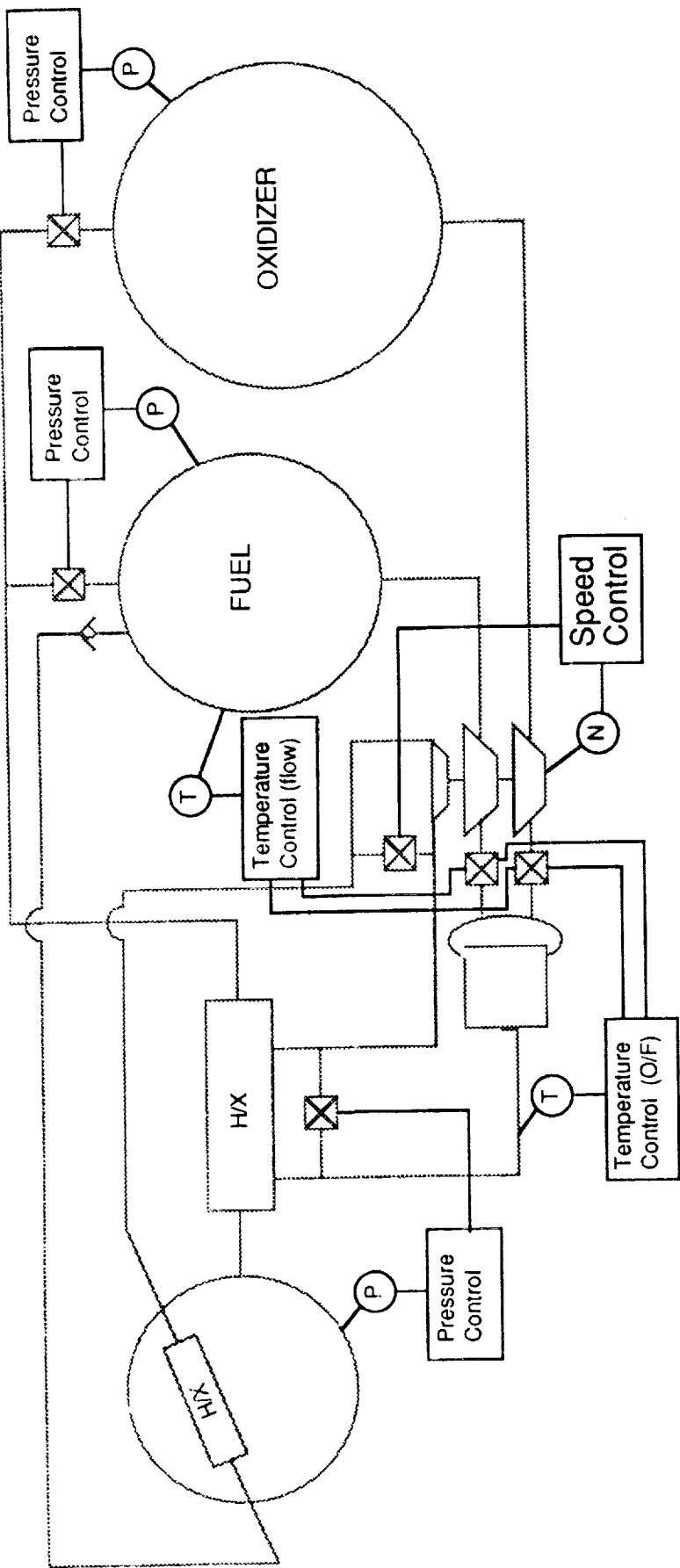
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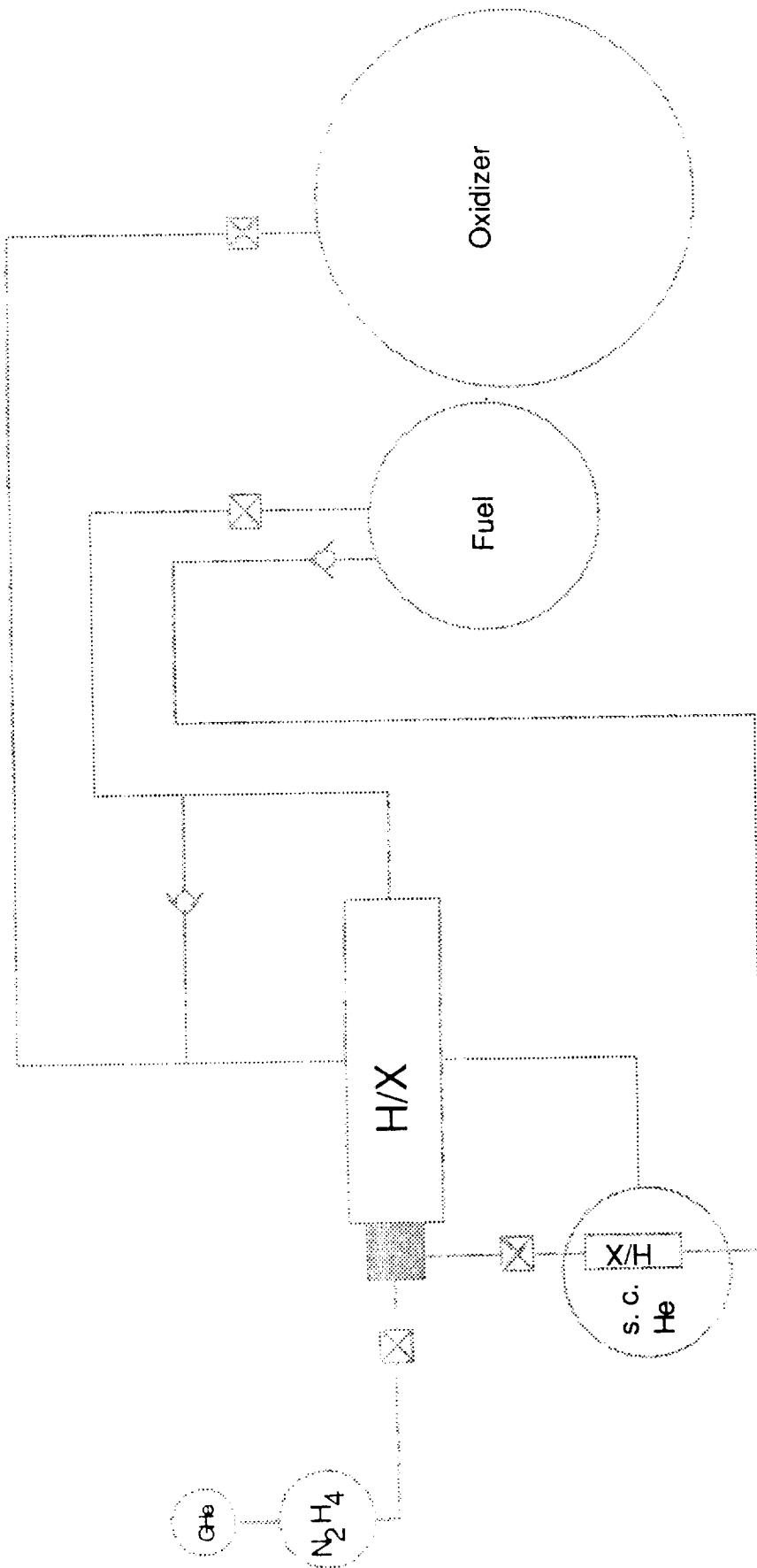


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Turbo-pump Exhausting Into Tank

Candidate #5





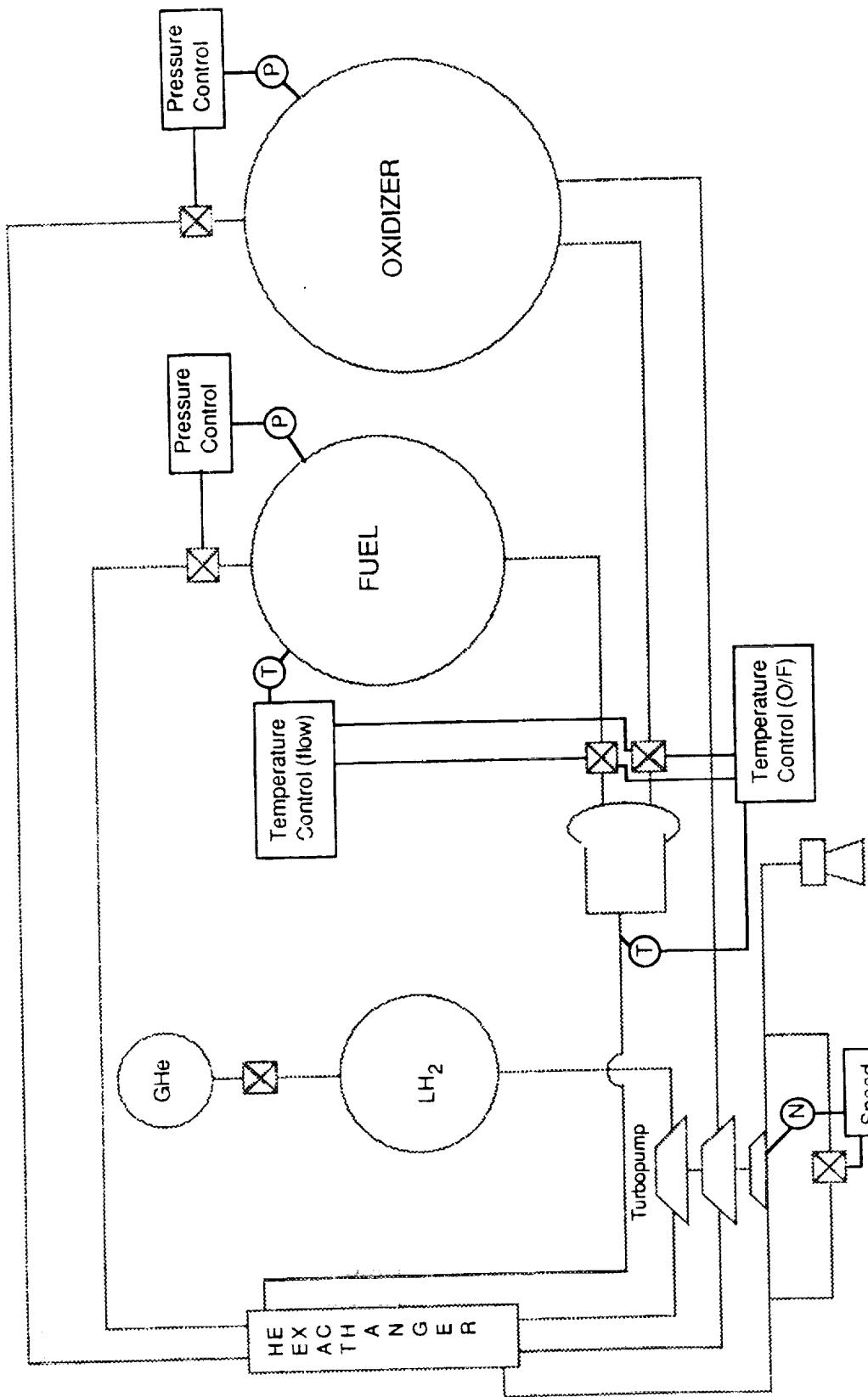
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Candidate #7

Hydrazine Energy Source

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Candidate #10
Turbo-pump With Overboard Exhaust and
Hydrogen as Pressurizing Gas

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PROPELLANT TANK PRESSURIZATION TECHNOLOGY PROGRAM
Configuration Trade Study - Phase II

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FLIGHT PRESSURIZATION SYSTEM-CONTROL SYSTEM SCORING

EVALUATION CRITERIA (SCORE OF 0=WORST,10=BEST)	ALTERNATIVE CONCEPTS					WEIGHTING (%)
	# 2	# 3 A	# 4 A - 1	# 4 A - 2	# 4 Z	
ACTIVE LOOP SCORE	10	6	8	10	8	10
START-UP UNIQUE	10	10	10	10	10	20
CONTROL SIMPLICITY	10	10	10	10	10	40
INSTRUMENTATION SIMPLICITY	10	10	7	7	8	20
SENSORS SCORE	8	9	7	7	4	3
FINAL SCORE (10=BEST)	9.8	9.5	8.9	9.1	8.8	8.9

NOTE: THESE ARE THE LATEST UPDATES AS OF 12/07/89.

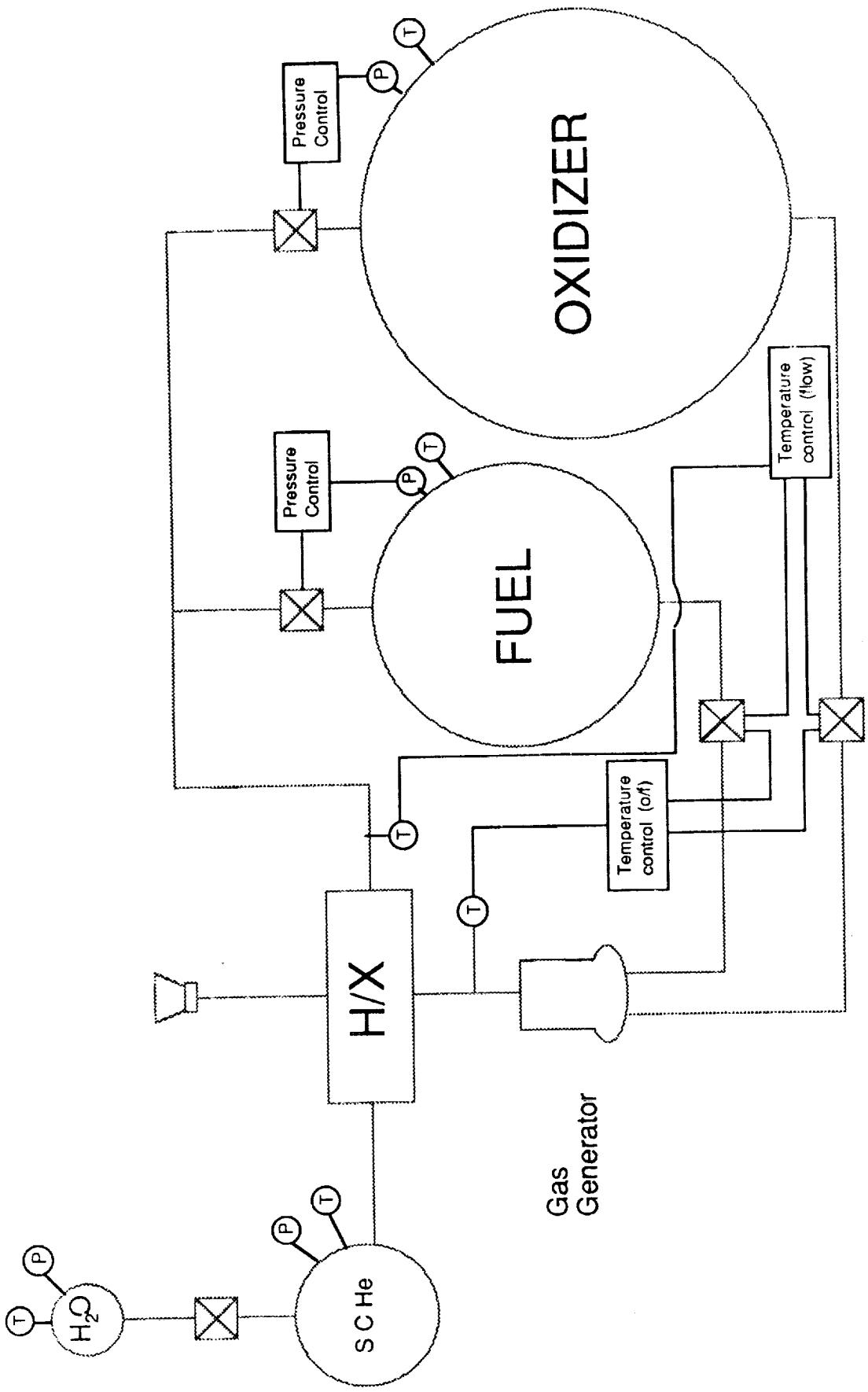
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FLIGHT PRESSURIZATION SYSTEM-CONTROL SYSTEM RATIONALE

EVAL. CRITERIA	ALTERNATIVE CONCEPTS						EXPLANATION
	# 2	# 3 A	# 4 A - 1	# 4 A - 2	# 4 Z	# 4 Z - 1	
Active loops required	3	5	4	3	4	3	
ACTIVE LOOP SCORE	10	6	8	10	8	10	3 ACTIVE LOOPS = 10; DROP 2 PTS. FOR EACH EXTRA ACTIVE LOOP
START-UP UNIQUE	10	10	10	10	10	10	NO SPECIAL START-UP EQUIPMENT REQUIRED = 10; DESIGN START-UP EQUIPMENT = 0
CONTROL SIMPLICITY	10	10	10	10	10	10	SIMPLE SYSTEM =10; ADDITIONAL CONTROL LOOPS = 9; SOME CONTROL DIFFICULTY=7; EXTREME DIFFICULTY = 0
INSTR. SIMPLICITY	10	10	7	7	8	8	EASY, ST. FWD. =10; ST. FWD., BUT COMPLEX = 9; DIFFICULT. MEAS. = 7; VERY DIFFICULT, LOCATION DEPENDENT = 4
Sensor sets required	10	9	11	11	14	15	
SENSORS SCORE	8	9	7	7	4	3	8 SETS =10; DROP 1 PT FOR EACH ADDITIONAL SET

NOTE: THESE ARE THE LATEST UPDATES AS OF 12/07/89.

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Candidate #2

Honeywell

Candidate #2 → Gas Generator/Heat Exchanger/Steam

Fuel and LOX Tank Pressure Control:

The baseline concept is to use a simple proportional pressure regulator at the inlet to the tank. This allows the major pressure drop between the He storage tank and the fuel and LOX tanks to occur at the point of control, resulting in a simpler control with good accuracy.

Primary Heat Addition (Pressurant Temperature Control):

The system configuration has a heat exchanger between the He storage tank and the fuel and LOX tanks. The temperature control is accomplished by passing constant temperature products of combustion through the hot side of the heat exchanger.

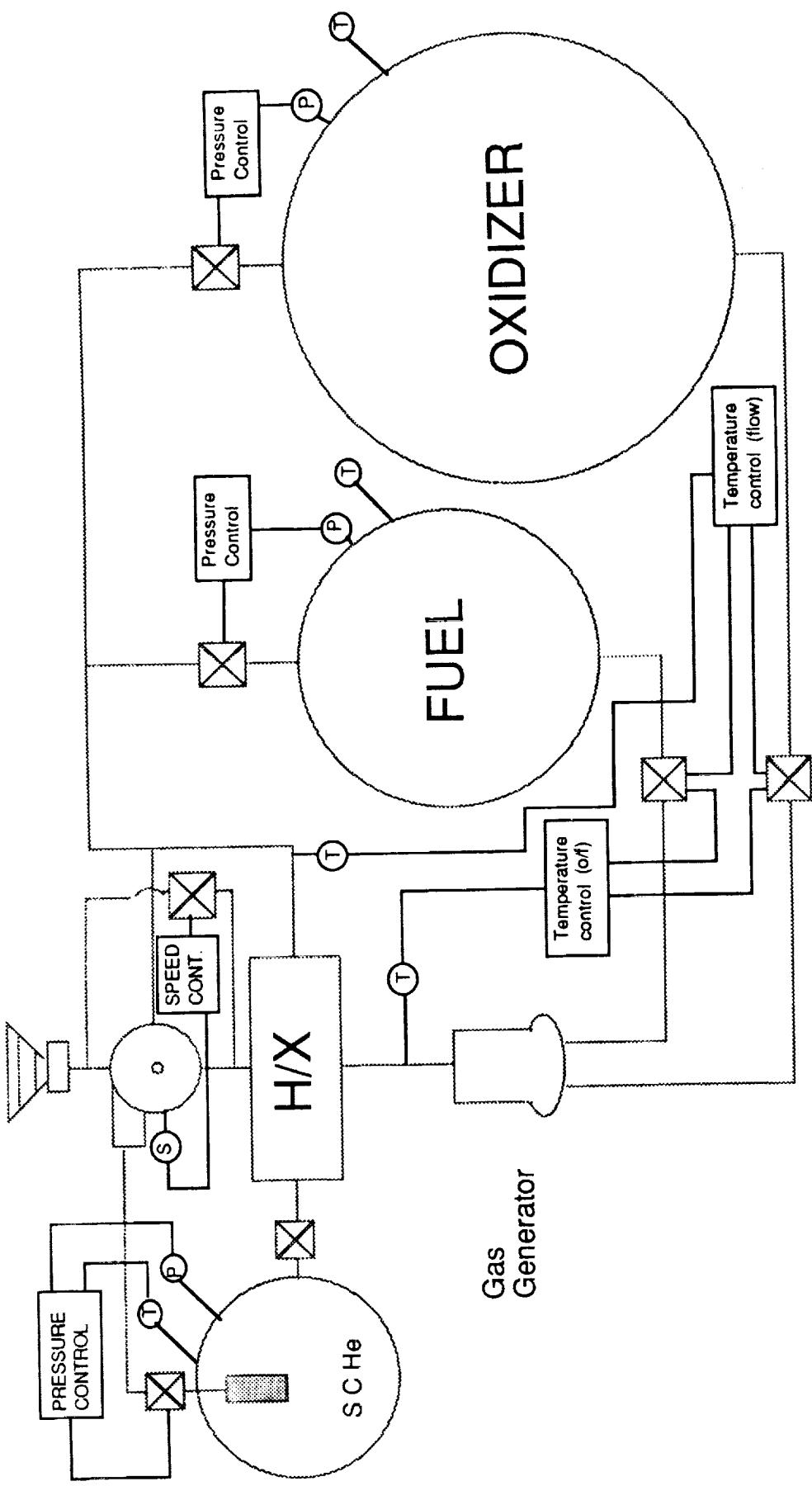
There is a positive feedback coupling between the He storage tank and the fuel and LOX tanks. The temperature control tends to be a constant heat flux device over short durations of time. 30 seconds into the mission when the He flow requirement is reduced to three quarters there is a temperature rise because of reduction in mass flow for a constant heat flux. The increased He temperature causes a corresponding reduction in the pressure regulator flow requirement resulting in an increased disturbance

Gas Generator:

Gas Generator is flow controlled in response to the heat exchanger cold side exit temperature.

The gas generator is operated fuel rich with a open loop O/F control. Only a minor change in the control algorithm would include active temperature control of the gas generator. This would result in a more accurate gas generator temperature control with no increase in complexity to the control valving required.

Secondary Heat Addition (He tank heat addition): hot water which freezes as it mixes with the cold He. The water tank initial conditions are 3000 psia at 700 F. This is a saturated liquid state. The water removed from the tank is saturated liquid and some of the remaining liquid flashes to sustain the pressure.

Candidate #3A**Honeywell**

Candidate #3a → Stored Gas - H/X and Heater

Fuel and LOX Tank Pressure Control:

The baseline concept is to use a simple proportional pressure regulator at the inlet to the tank. This allows the major pressure drop between the He storage tank and the fuel and LOX tanks to occur at the point of control, resulting in a simpler control with good accuracy.

Primary Heat Addition (Pressurant Temperature Control):

The system configuration has a heat exchanger between the He storage tank and the fuel and LOX tanks. The temperature control is accomplished by passing constant temperature products of combustion through the hot side of the heat exchanger.

There is a positive feedback coupling between the He storage tank and the fuel and LOX tanks. The temperature control tends to be a constant heat flux device over short durations of time. 30 seconds into the mission when the He flow requirement is reduced to three quarters there is a temperature rise because of reduction in mass flow for a constant heat flux. The increased He temperature causes a corresponding reduction in the pressure regulator flow requirement resulting in an increased disturbance.

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The gas generator is operated fuel rich with a open loop O/F control. Only a minor change in the control algorithm would include active temperature control of the gas generator. This would result in a more accurate gas generator temperature control with no increase in complexity to the control valving required.

Secondary Heat Addition (He tank heat addition):

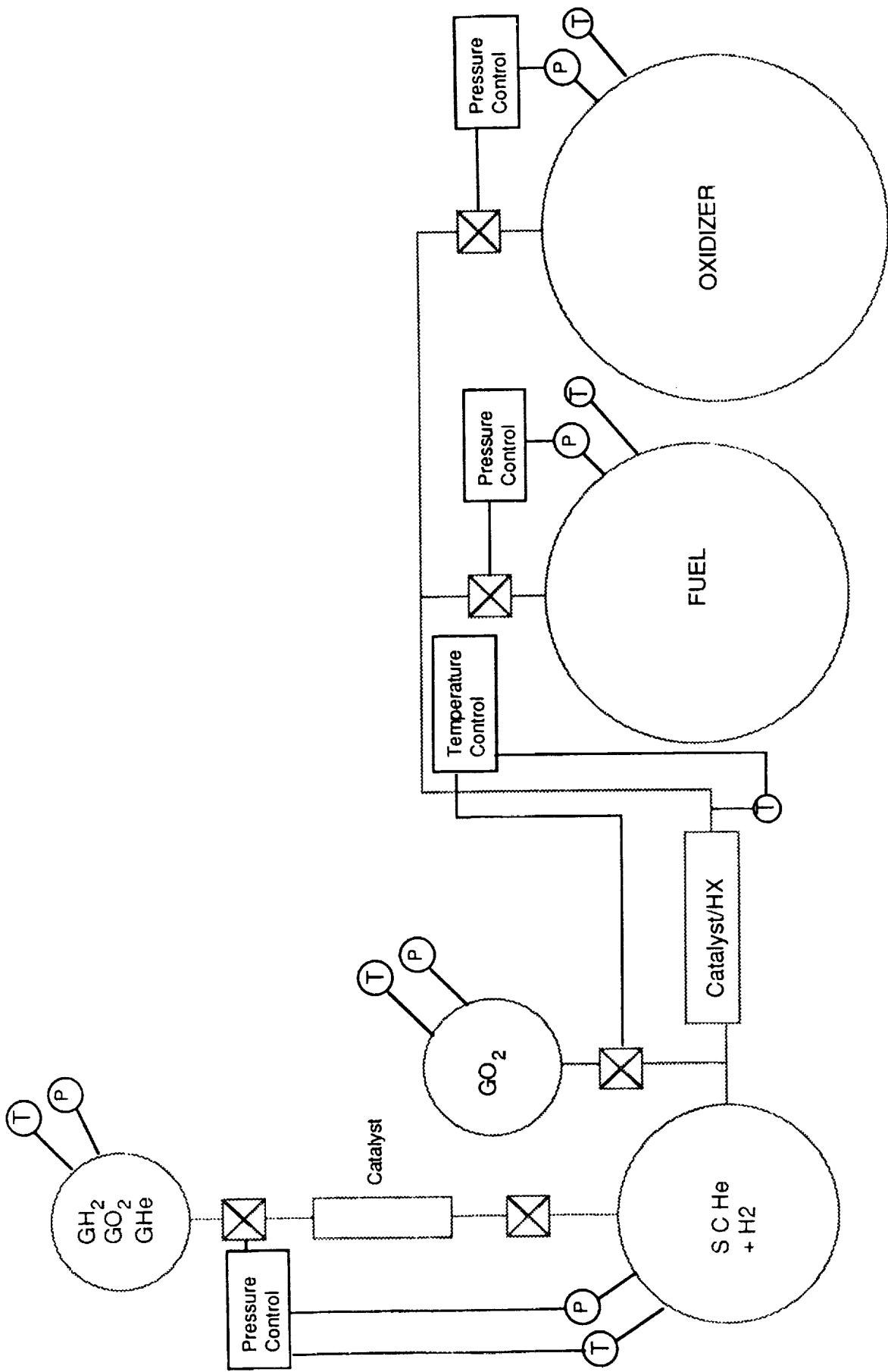
The He tank pressurization is accomplished by recirculating hot He from the heat exchanger exit. The recirculation is accomplished by use of a turbine driven fan (low pressure ratio turbo-compressor). The energy to drive the turbine is the waste heat from the hot side of the heat exchanger. The speed of the turbine is controlled by bypassing the excess flow around the turbine.

The He tank pressure profile can be accomplished two ways. Run the turbine at constant speed for the duration of the mission with the pressure profile having a termination in the 1500 to 1600 psia range. A more precise pressure profile can be accomplished by adding a throttle valve between the fan and the He tank.

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Candidate #4a-1

Honeywell



Candidate #4A-1 ⇒ Catalyst Alternate

Fuel and LOX Tank Pressure Control:

The baseline concept is to use a simple proportional pressure regulator at the inlet to the tank. This allows the major pressure drop between the He and H₂ storage tank and the fuel and LOX tanks to occur at the point of control, resulting in a simpler control with good accuracy.

Primary Heat Addition (Pressurant Temperature Control):

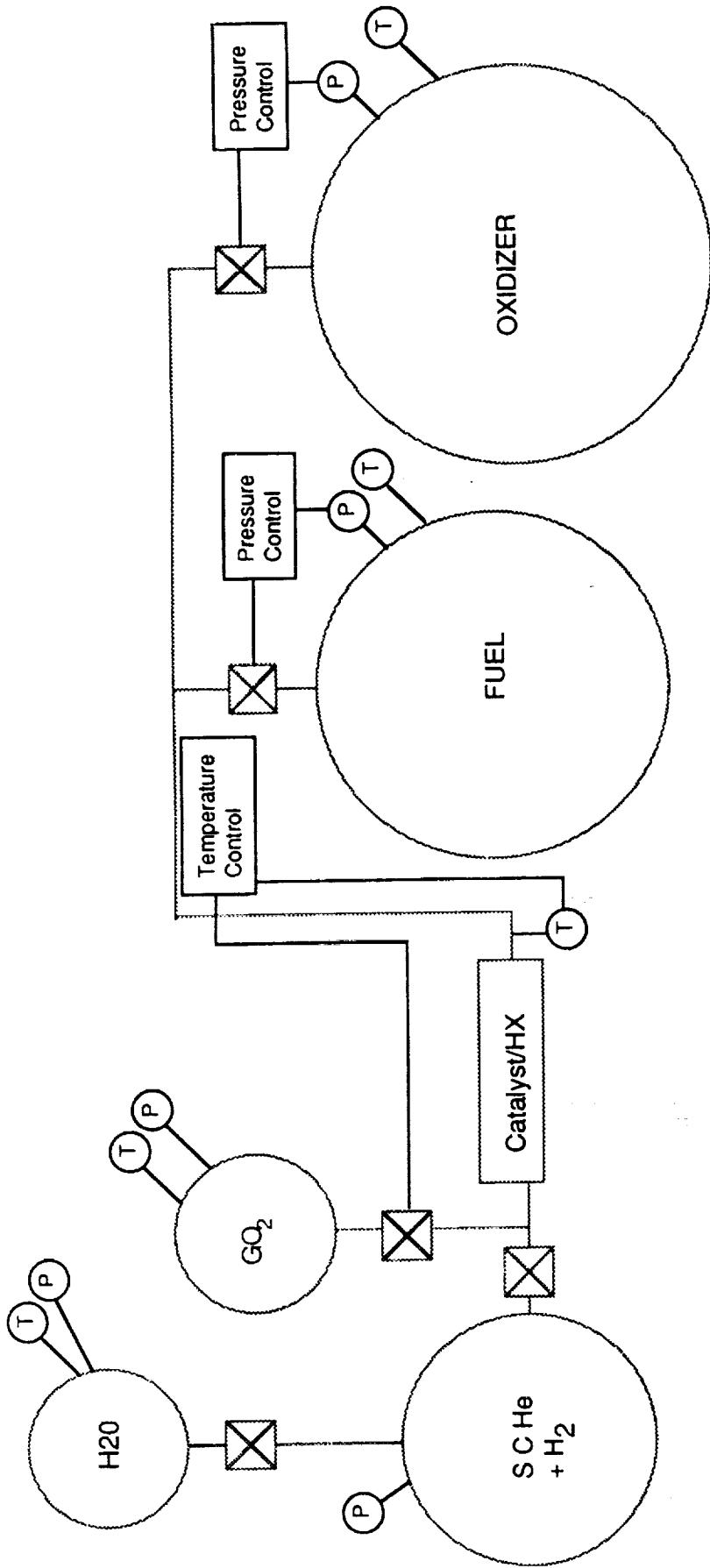
The primary heat addition to the helium occurs in a catalyst bed from a hydrogen-oxygen reaction. The helium and hydrogen are mixed and stored in a supercritical helium tank. The outlet temperature of the catalyst bed is controlled by metering the flow rate of oxygen to the catalyst.

The transient response of the system will be faster than the heat exchanger gas generator system, but slower than the hydrogen-oxygen heater system.

The hydrogen-oxygen reaction will be close to stoichiometric at the beginning of the mission and will drift toward fuel rich as the helium dewar heats up, controlling the pressurant to a constant 1000 R.

Secondary Heat Addition (He tank heat addition):

The heat addition to the He tank is accomplished by adding a hot mixture of He and steam to the cold He. The He tank pressure is controlled to a prescribed schedule by metering the H₂/O₂/He flow through the secondary catalyst.



Candidate #4a-2

Honeywell

Candidate #4A-2 → Catalyst Alternate/Steam

Fuel and LOX Tank Pressure Control:

The baseline concept is to use a simple proportional pressure regulator at the inlet to the tank. This allows the major pressure drop between the He storage tank and the fuel and LOX tanks to occur at the point of control, resulting in a simpler control with good accuracy.

Primary Heat Addition (Pressurant Temperature Control):

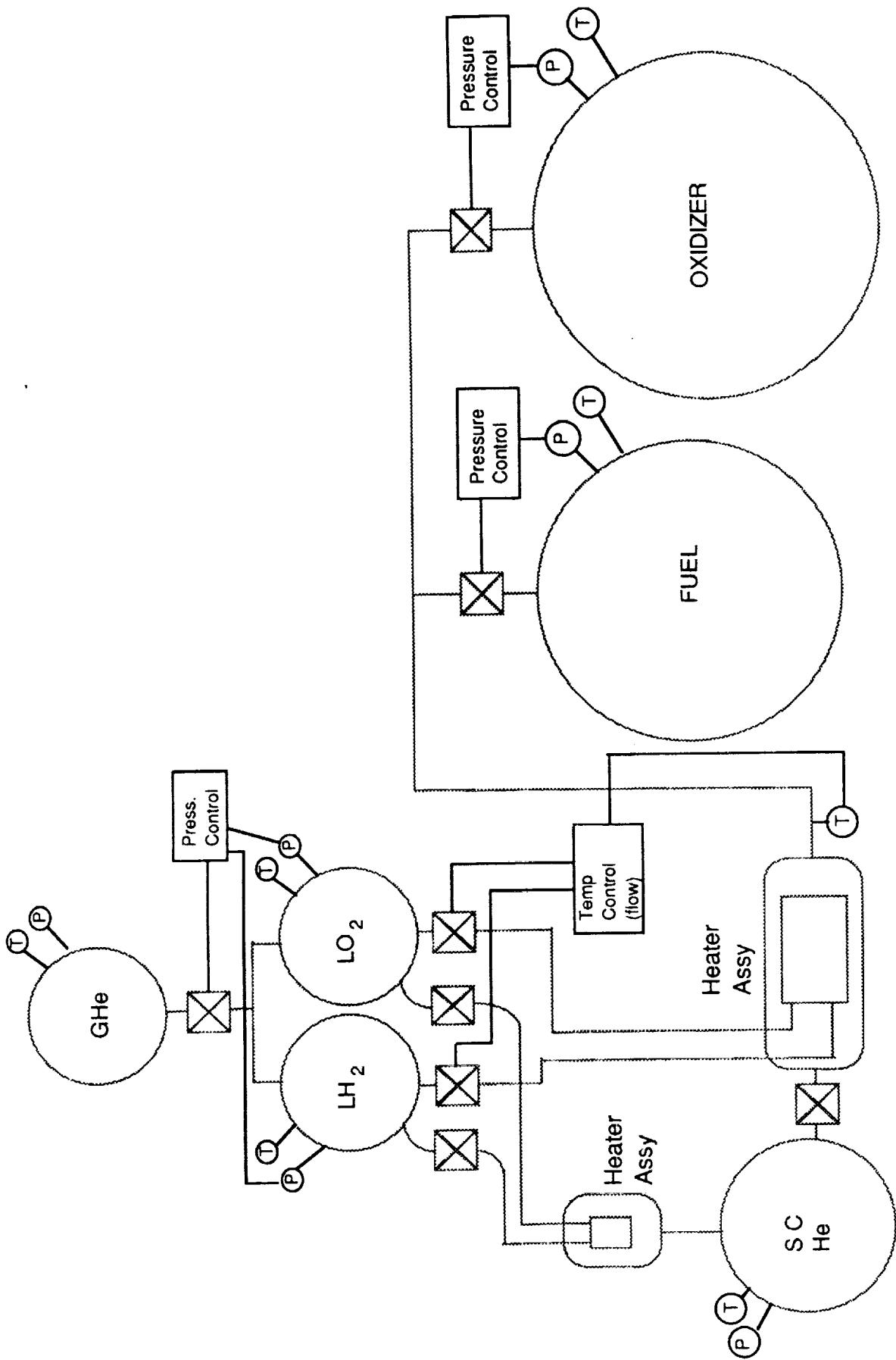
The primary heat addition to the helium occurs in a catalyst bed from a hydrogen-oxygen reaction. The helium and hydrogen are mixed and stored in a supercritical helium tank. The outlet temperature of the catalyst bed is controlled by metering the flow rate of oxygen to the catalyst.

The transient response of the system will be faster than the heat exchanger gas generator system, but slower than the hydrogen-oxygen heater system.

The hydrogen-oxygen reaction will be close to stoichiometric at the beginning of the mission and will drift toward fuel rich as the helium dewar heats up, controlling the pressurant to a constant 1000 R.

Secondary Heat Addition (He tank heat addition):

The heat addition to the He tank is accomplished by adding hot water which freezes as it mixes with the cold He. The water tank initial conditions are 3000 psia at 700 F. This is a saturated liquid state. The water removed from the tank is saturated liquid and some of the remaining liquid flashes to sustain the pressure.

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Candidate #4Z \Rightarrow LH₂/LO₂/Helium Heater

Fuel and LOX Tank Pressure Control:

The baseline concept is to use a simple proportional pressure regulator at the inlet to the tank. This allows the major pressure drop between the He storage tank and the fuel and LOX tanks to occur at the point of control, resulting in a simpler control with good accuracy.

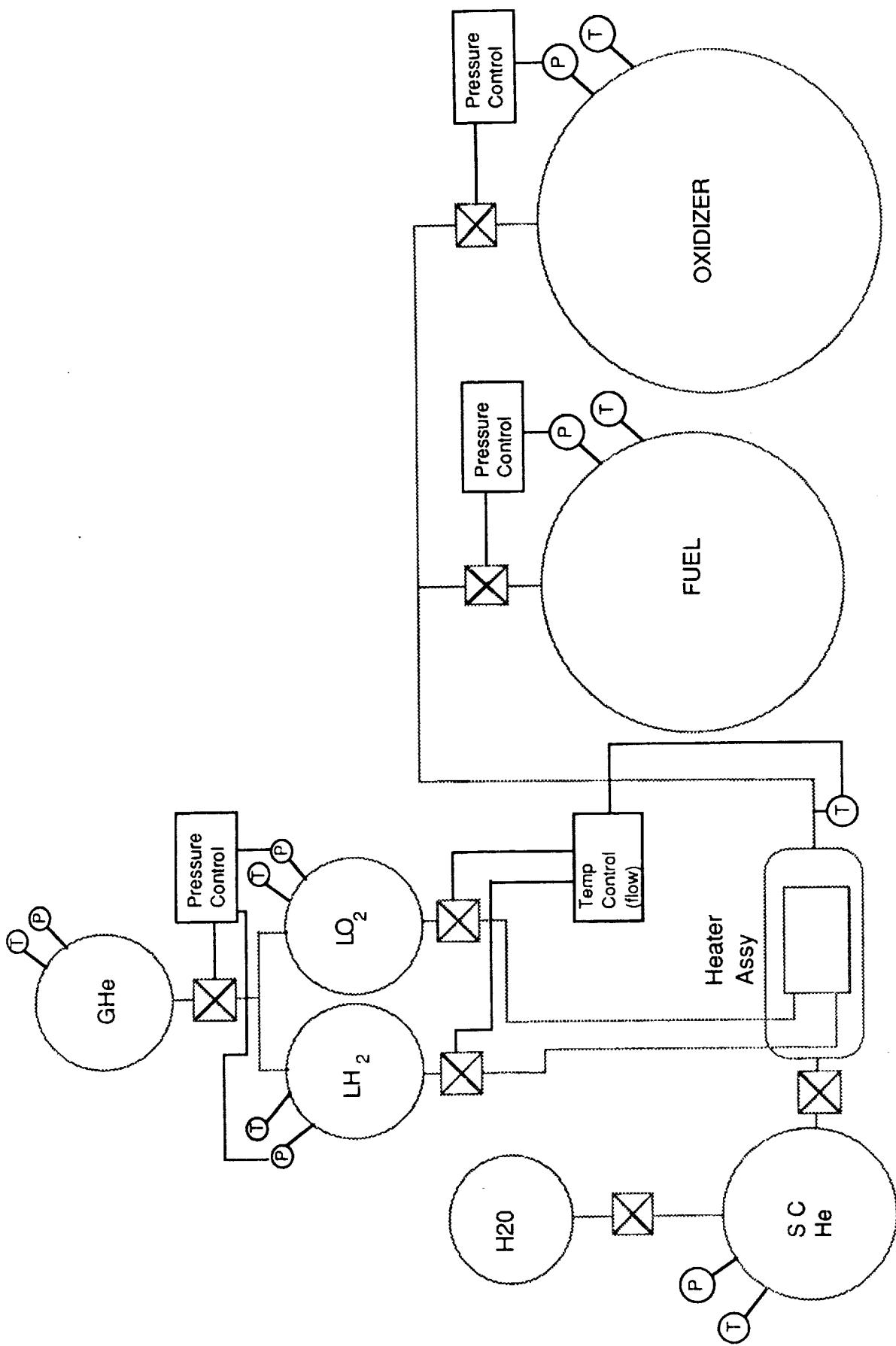
Primary Heat Addition (Pressurant Temperature Control):

The primary heat source is a hydrogen oxygen heater with a helium diluent to reduce the outlet temperature to 1000 R. The hydrogen and oxygen flows are controlled in unison to maintain the heater outlet temperature. The hydrogen/oxygen flow ratio is maintained to result in stoichiometric mixture into the heater. The pressure of the LH₂ and LOX tanks is held at a constant delta above the supercritical helium tank. This allows the control valves and injectors to operate with a constant pressure across them.

Secondary Heat Addition (He tank heat addition):

The secondary heat source is also a hydrogen-oxygen heater in the He tank. The hydrogen and oxygen flow rates are maintained to constant stoichiometric ratio by orifice selection and the constant delta pressure across the orifice injector combination. This provides a constant heat addition to the He tank.

CANDIDATE 4Z-1

Honeywell

Candidate #4Z-1 \Rightarrow LO₂/LH₂/Helium/Steam Heater

Fuel and LOX Tank Pressure Control:

The baseline concept is to use a simple proportional pressure regulator at the inlet to the tank. This allows the major pressure drop between the He storage tank and the fuel and LOX tanks to occur at the point of control, resulting in a simpler control with good accuracy.

Primary Heat Addition (Pressurant Temperature Control):

The primary heat source is a hydrogen oxygen heater with a helium diluent to reduce the outlet temperature to 1000 R. The hydrogen and oxygen flows are controlled in unison to maintain the heater outlet temperature. The hydrogen/oxygen flow ratio is maintained to result in stoichiometric mixture into the heater. The pressure of the LH₂ and LOX tanks is held at a constant pressure delta above the supercritical helium tank. This allows the control valves and injectors to operate with a constant pressure across them.

Secondary Heat Addition (He tank heat addition):

The heat addition to the He tank is accomplished by adding hot water which freezes as it mixes with the cold He. The water tank initial conditions are 3000 psia at 700 F. This is a saturated liquid state. The water removed from the tank is saturated liquid and some of the remaining liquid flashes to sustain the pressure.

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**PROPELLANT TANK PRESSURIZATION
TECHNOLOGY PROGRAM**

**Tank Pressurization System Performance
Evaluation**

Honeywell

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OBJECTIVE

- Create models of sufficient detail to yield preliminary control designs and verification.

REQUIREMENTS

- Oxidizer and fuel tank pressures to be controlled to within ± 5.0 percent
- The primary heat source is used to heat the helium to constant temperature.
- The secondary heat source will be sufficient to maintain pressure in the helium tank high enough to complete the 120 second mission.
- System LO₂ volume flow rate 112.4 ft³/sec.
- System RP-1 volume flow rate 65.9 ft³/sec.
- Initial ullage volume of 5%.
- Maximum LO₂ and RP-1 ullage temperature 800°R
- Maximum He pressurant temperature 1000°R exiting primary heat source.

ASSUMPTIONS

- The plumbing losses will be ignored or combined with a valve or an orifice.
- Some of the tanks will be simplified to a source of fluid at a known pressure without detailed modeling of the tank or pressure control.(This was the case for the liquid oxygen and liquid hydrogen tanks for the heaters in system 4Z)
- System LO₂ and RP-1 volume flow rates increased by 10 - 20% to account for piping and conduction losses.
- Initial LO₂ and RP1 ullage volume 400 ft³.

CANDIDATES TO BE MODELLED

- System 2--Gas Generator/Heat Exchanger/Steam
- System 4A2--Catalyst Alternate/Steam
- System 4Z--LH₂/LO₂/Helium Heater

SIMULATION TOOL

- Integrated Systems MATRIXX™ on a VAX workstation 2000
- Block diagram representation of system
- Hierarchical system build functionality
- Controls analysis toolbox

SIMULATION RUN PARAMETERS

- 120 second runtime
- Fourth order Runge-Kutta integration
- 40 millisecond integration rate
- Analog control system assumed

SIMULATION ANALYSIS RESULTS

- All 3 systems modeled met performance requirements
- System 4Z is the most robust from a tank pressurization control system performance viewpoint.

SYSTEM 2

Model Development Configuration 2 - Steam Expulsion and Gas Generator Heating

The system shown is figure 1. The components which were simulated and the associated controls are described in the following text.

GG/HX/Steam

Candidate 2

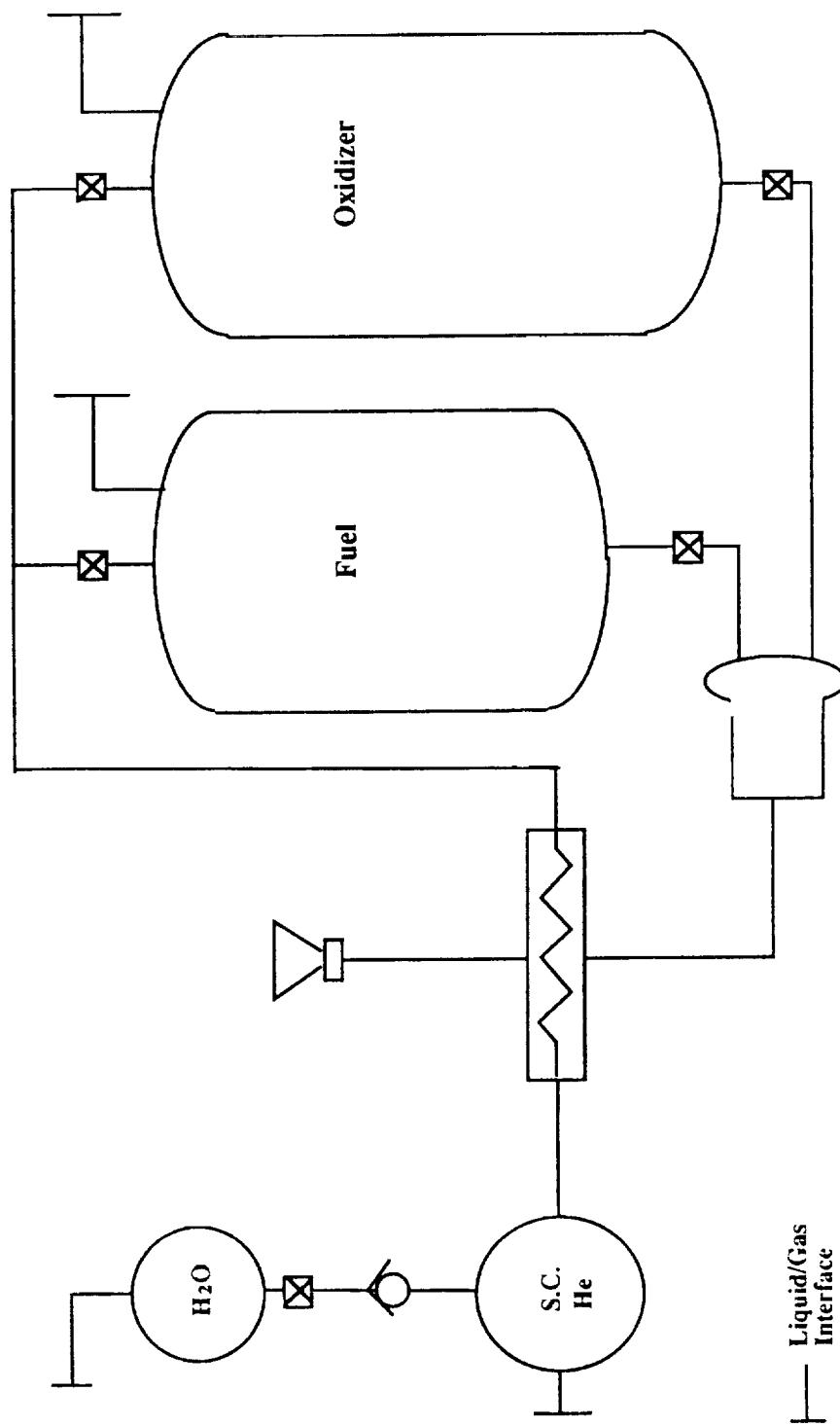
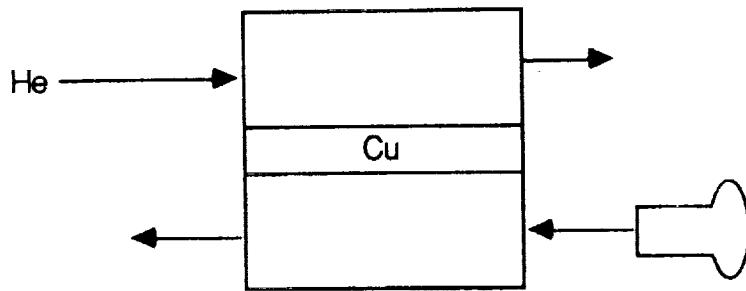


Figure 1

Heat Exchanger Model



The heat exchanger is modeled as a counter flow Hx with Cu core, and is divided into ten (10) segments.

The state variables for each segment are He temperature and Cu temperature. The gas side has a short time constant so it is modeled algebraically.

He side

$$\frac{dT_{He}}{dt} = \frac{Q_{in} - Q_{out} + Q_{He}}{M_{He} C_{p,He}}$$

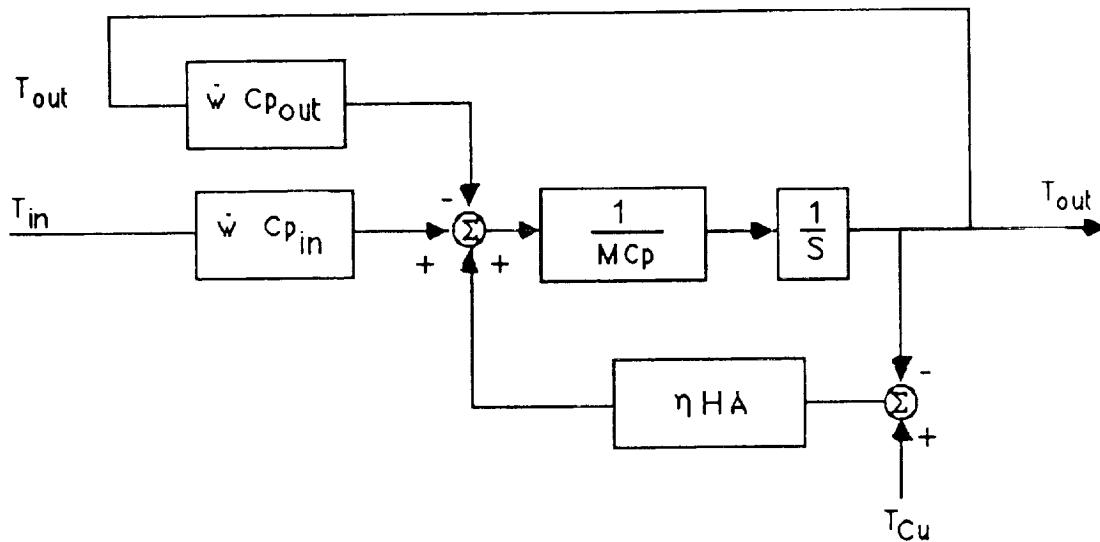
$$Q_{in} = \dot{w}_{in} T_{in} C_{p,in} \quad \frac{\text{lb}}{\text{sec}} \cdot \text{R} \quad \frac{\text{BTU}}{\text{lb} \cdot \text{R}}$$

$$Q_{out} = \dot{w}_{in} T_{out} C_{p,out}$$

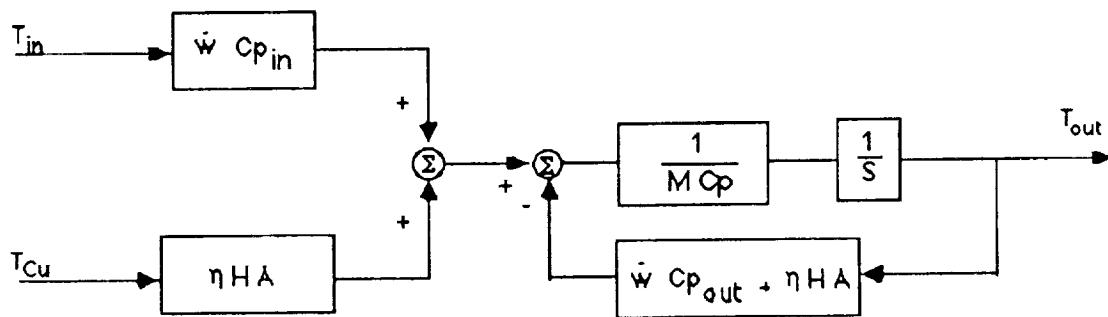
$$Q_{He} = (T_{Cu} - T_{He}) \eta HA \quad \text{R} \quad \frac{\text{BTU}}{\text{sec in}^2 \cdot \text{R}} \quad \text{in}^2$$

The Q's have units of BTU/sec.

T_{out} is the value of the He temperature state variable and $T_{He} = T_{out}$. The flow rate is constant throughout the Hx.



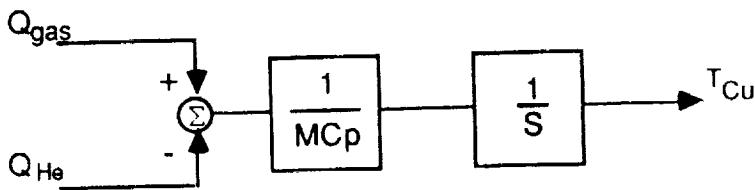
or



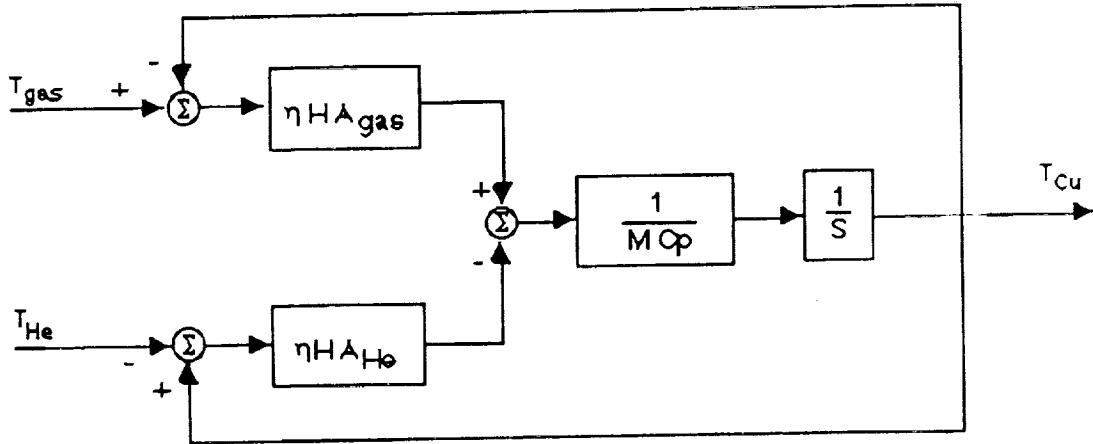
The outlet temperature of the first segment is the inlet temperature of the second, etc.

Core

The core conduction is ignored.



Since both Q_{He} and Q_{gas} are a function of T_{Cu} , this becomes closed loop.



The core state variables are only tied together through the He and gas flows.

Gas Side

The gas side has a short time constant. The combustion products come in at 2100°R and 525 Psia, which yields a low (ρ) ρ and thus a low $M Cp$ (thermal capacitance). The time constant for the first segment

$$1 / \tau_{\text{gas}} = \frac{\dot{w} C_p_{\text{out}} + \eta H_A}{MC_p}$$

$$\begin{aligned} MC_p &= \frac{PV}{RT} C_p \\ &= \frac{525 * 7.561}{\frac{1545}{20.3} * 2000} * 1.44 = 0.03755 \frac{\text{BTU}}{\text{sec} \text{ } ^\circ \text{R}} \end{aligned}$$

$$\eta H_A = 132.846 \frac{\text{BTU}}{\text{sec} \text{ } ^\circ \text{R}}$$

$$\tau_{\text{gas}} = 129.78 \mu \text{sec.}$$

Where as the He time constant varies between

$$26.06\text{msec} < \tau_{\text{He}} < 43.89\text{msec}$$

A 200:1 step size improvement can be accomplished by finding an algebraic solution to the gas side equations. If the change in density is neglected in a segment then the gas velocity is a constant and the temperature vs. length and the temperature vs. time is an exponential equation. By equating the transport time of the gas and the time constant of the gas, a solution is obtained.

$$1 / \tau_t = \frac{\dot{w} C_p + \eta H A}{M C_p}$$

$$\tau_v = \frac{M}{\dot{w}} = \frac{P V}{R T \dot{w}} \frac{\text{sec}}{\text{segment}}$$

$$\tau_t = \frac{M C_p}{\dot{w} C_p + \eta H A}$$

$$\tau_t = \frac{\frac{P V}{R T} C_p}{\dot{w} C_p + \eta H A}$$

$$\tau_t = \frac{P V C_p}{R T (\dot{w} C_p + \eta H A)^{0.8}}$$

As the gas travels through a segment the temperature varies

$$T_{\text{gas}} = T_{\text{Cu}} + (T_{\text{in}} - T_{\text{Cu}}) e^{-R\ell}$$

$$\ell = 1 \text{ segment} \quad R = \frac{\tau_v}{\tau_t} \frac{1}{\text{segment}} \quad (\text{relaxation rate})$$

$$R = \frac{\frac{PV}{RT\dot{w}}}{\frac{PV Cp}{RT(\dot{w}Cp + k\dot{w}^{0.8})}}$$

which reduces to:

$$R = \frac{\dot{w}Cp + k\dot{w}^{0.8}}{\dot{w}Cp} = \frac{\dot{w}Cp + \eta HA}{\dot{w}Cp}$$

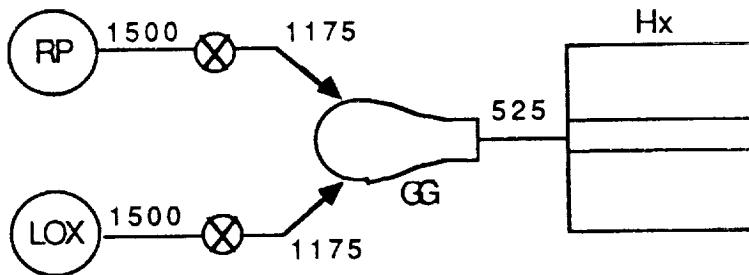
$$T_{out} = T_{Cu} + (T_{in} + T_{Cu}) e^{-R}$$

the heat transfer

$$Q = (T_{in} - T_{out}) \dot{w} Cp$$

Gas Generator

The Hx inlet pressure is 563 Psia and the outlet pressure is 500. For this simplified analysis the pressure drop in the Hx will be ignored.



Splitting the pressure drop 2/3 to 1/3 with the nozzles and the valve, the maximum flow pressure drops are as shown. This is with a flow rate of 110 lbs/sec and a MR = 0.3.

$$\dot{w} = A \sqrt{\rho g \Delta P}$$

$$MR = 0.3 = \frac{\dot{w}_o}{\dot{w}_f} \Rightarrow \dot{w}_o = 0.3 \dot{w}_f$$

$$\dot{w}_o + \dot{w}_f = 110$$

$$1.3 \dot{w}_f = 110$$

$$\dot{w}_f = 84.62 \text{ lb/sec} \quad \dot{w}_o = 25.38 \text{ lb/sec}$$

Valves

$$\text{Fuel} \quad kA_v = 4.69$$

$$\text{LOX} \quad kA_v = 1.41$$

Nozzles

$$kA_n = 3.32$$

$$kA_n = 0.995$$

$$w^2 = kA^2 \Delta P$$

$$\frac{\dot{w}^2}{kA_v^2} + \frac{\dot{w}^2}{kA_n^2} = \Delta P$$

$$\dot{w}^2 = \Delta P \frac{kA_n^2 + kA_v^2}{kA_n^2 + kA_v^2}$$

$$\dot{w}^2 = kA_n * kA_v \sqrt{\frac{\Delta P}{kA_n^2 + kA_v^2}}$$

$$\frac{d\dot{w}}{dA_v} = kA_n \sqrt{\frac{\Delta P}{kA_n^2 + kA_v^2}} - kA_n kA_v \sqrt{\Delta P} \frac{1}{2} \left(kA_n^2 + kA_v^2 \right)^{-\frac{3}{2}} 2kA_v$$

$$\frac{d\dot{w}_f}{dA} = \frac{d\dot{w}_o}{dA} = 6.009 \frac{\text{lb}}{\text{sec } kA_v}$$

Assume one volume for the gas side of the system. Include same volume for pipes.

$$V = 100 \text{ ft}^3$$

$$PV = MRT$$

$$P = \frac{MRT}{V}$$

Use an average temperature between GG temp and Hx exhaust temperature. For noise reduction from GG temperature fluctuations the model will use

$$P = \frac{R\bar{T}}{V} (\dot{w}_{in} - \dot{w}_{out})$$

The \dot{w}_{out} will be based on choked flow through exhaust nozzle.

$$\dot{w} = A P_k \sqrt{\frac{\gamma g}{TR} \left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma + 1}{\gamma - 1}}}$$

$$\dot{w} = 5.92623 \frac{P}{\sqrt{T}}$$

Use the nozzle flow for the flow through the heat exchanger.

Gas Generator Combustion

$$T_{MR=0.3} = 1300^{\circ}\text{F} = 1760^{\circ}\text{R}$$

$$T_{MR=1.75} = 4000^{\circ}\text{F} = 4460^{\circ}\text{R}$$

$$T = 1201.4 + 1862 * MR$$

Use a constant $C_p = 1.44$ and constant temperature, varying flow only.

LOX and Fuel Tanks.

$$PV = MRT$$

$$P = \frac{MRT}{V}$$

The volume is a function of time.

$$M = M_0 + \int_0^t \dot{w} dt$$

$$T_v = \frac{(T_w - T_v) \eta HA + (T_{in} - T_v) \dot{w} C_p}{MC_p}$$

where T_w is the tank wall temperature
 T_v is gas temperature over the liquid
 T_{in} is the temperature of the gas entering the tank.

The first term in the numerator is the heat loss to the tank. The second term is the excess heat of the incoming gas. In the model, the heat transfer to the tank was approximated by an increase in volumetric flow of the LOX and RP.

A is a function of time

$$A = A_0 + k_a t$$

Steam and He Tanks

The water comes out as saturated liquid. This means that the enthalpy of the remainder will drift upward. If the tank enthalpy hits saturated vapor, then there will be a change in density and enthalpy of the fluid removed. The fluid removed will be saturated vapor instead of saturated liquid.

Simulation

The ΔP between the H_2O and He tanks will set the flow rate between the tanks. This will be simulated as an incompressible flow, with the pressure drop occurring at the valve with the outlet into the He tank.

The state variables used will be total energy of the contents of the tank and the mass.

$$\begin{array}{ll} E & \text{BTU} \\ M & \text{lb}_m \end{array}$$

The mass flow out will be at an energy level of saturated liquid.

$$\frac{E}{M} = h \quad \frac{\text{BTU}}{\text{lb}}$$

The volume of the tank divided by total mass give specific volume

$$\frac{V}{M} = v \quad \frac{\text{ft}^3}{\text{lb}}$$

The intersection of the v and h lines will give pressure and thus h_{sl} and h_{sv} .

Parameters needed for the water.

$$h_{sl} \quad P \quad T \quad h_{sv} \quad v \text{ or } \rho$$

Initial Condition for Steam

$$\begin{aligned} v &= 0.034310 \text{ ft}^3/\text{lb} \\ h &= 802.5 \text{ BTU/lb} \end{aligned}$$

As the liquid is extracted from the tank, the enthalpy drift across the dome toward the saturated vapor boundary. When the tank enthalpy is:

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$$h_t \leq 0.1 h_{sl} + 0.9 h_{sv}$$

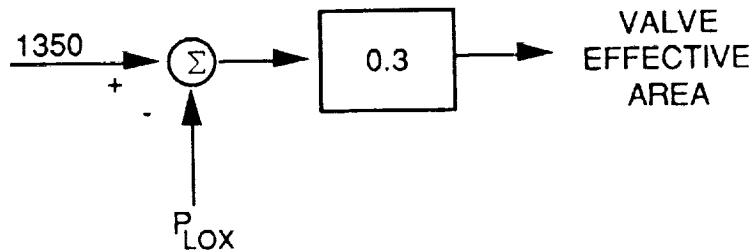
the enthalpy exiting the tank becomes:

$$h_{exit} = h_{sl} + (h_{sv} - h_{sl}) \left[\frac{h_t - h_{se}}{h_{sv} - h_{sl}} - 0.9 \right] 10$$

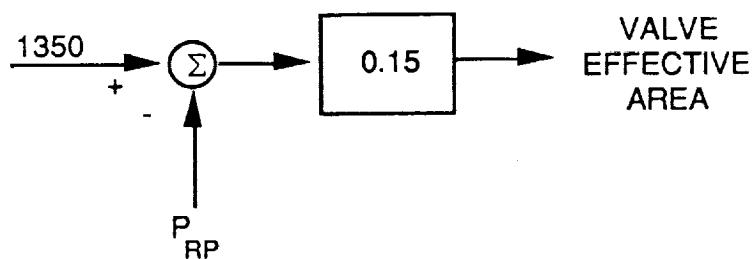
Control Design

The pressure regulators on the LOX and RP tanks were modeled as simple proportional regulators. If the major pressure drop has to move from the tank to upstream of the primary heat source an integral control will have to be used (minor impact to control system design).

LOX Tank

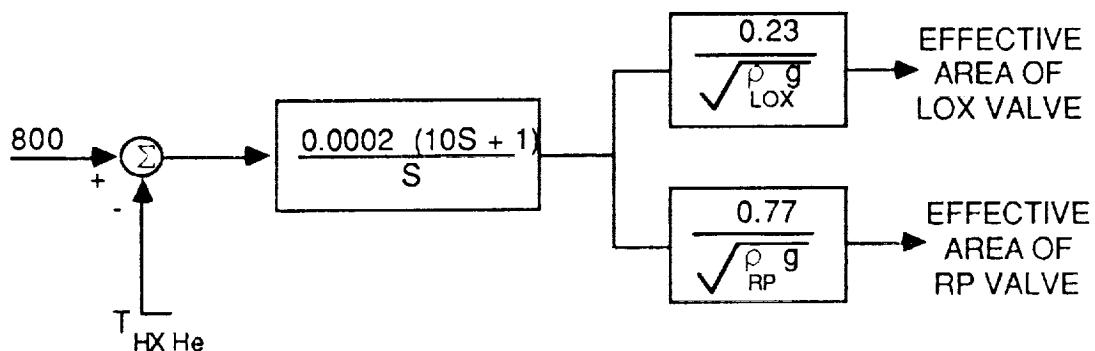


RP Tank



Primary Heat Source

The primary heat source is controlled by the total mass flow through the hot side of the heat exchanger.



ρ_{LOX} density of LOX ~ $\frac{\text{lbm}}{\text{in}^3}$

ρ_{RP} density of RP ~ $\frac{\text{lbm}}{\text{in}^3}$

g gravitational constant ~ $\frac{\text{in}}{\text{sec}^2}$

Value areas ~ in^2

SYSTEM 4A-2

This system (Figure 2) stores hydrogen with the helium. The primary heat source is a catalyst. Oxygen is added to the helium stream before entering the catalyst. The catalyst exit temperature is controlled by the amount of oxygen added to the stream. The oxidizer and fuel tanks are pressure controlled by regulators at the inlet to the tanks. The secondary heating is accomplished open loop by a steam blow down system into the helium/hydrogen tank.

Catalyst Alternate/Steam

Candidate 4 A-2

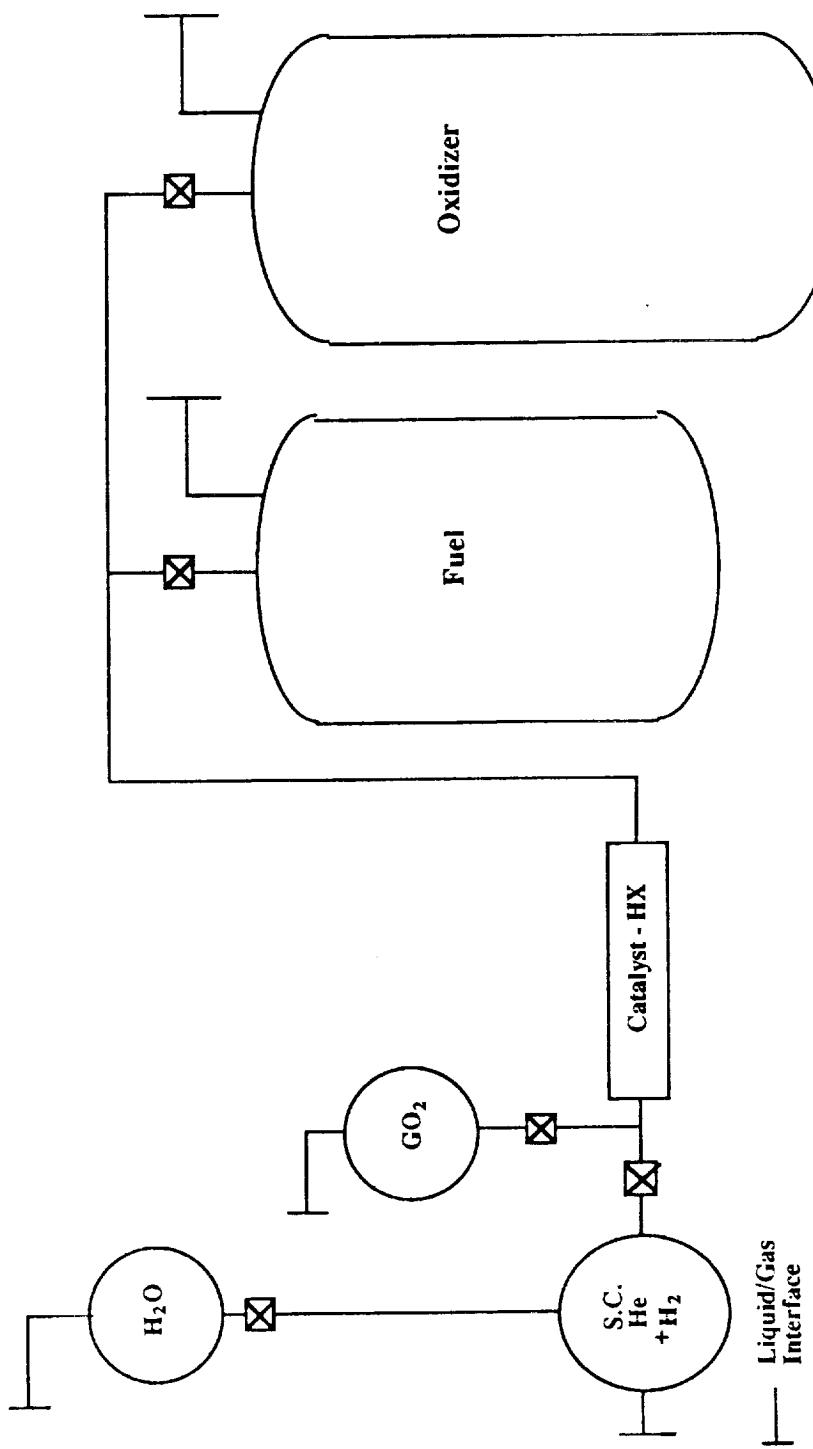
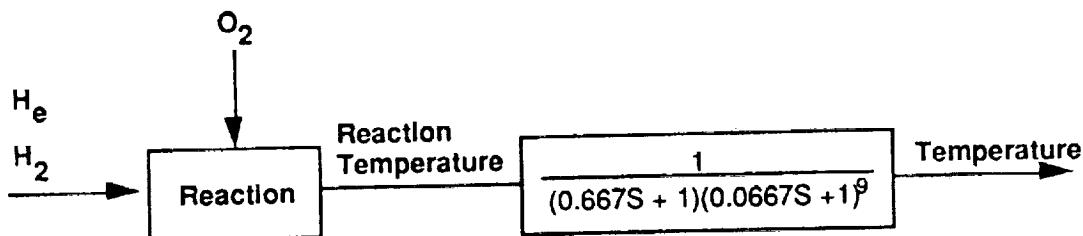


Figure 2

Primary Heat Source

The primary heat source is a catalyst. The data provided for the transient response was a start up condition. There was evidence of some catalyst quenching (figure 3). After approximately a half of a second, the temperature started to rise. The absence of data relating reaction rates as a function of temperature required that quenching be omitted. The model used was a 10th order.



A 300 R to 800 R transient is shown in Figure 4.

Gaseous Oxygen Tank

The oxygen is treated as an ideal gas

$$PV = MRT$$

$$P = \frac{MRT}{144V}$$

$$R = \frac{1545}{32} \frac{\text{ft lb}_f}{\text{lb}_m} = 48.28$$

M is the mass of oxygen in the tank and is a state variable.

T is 480°R

V is 179.59 ft³

144 in²/ft²

P is lb_f/in²

The flow from the oxygen tank and through the oxidant and fuel tank pressure regulators is:

CANDIDATE 4A-2 TRANSIENTS
He TEMP AT CATALYST BED OUTLET

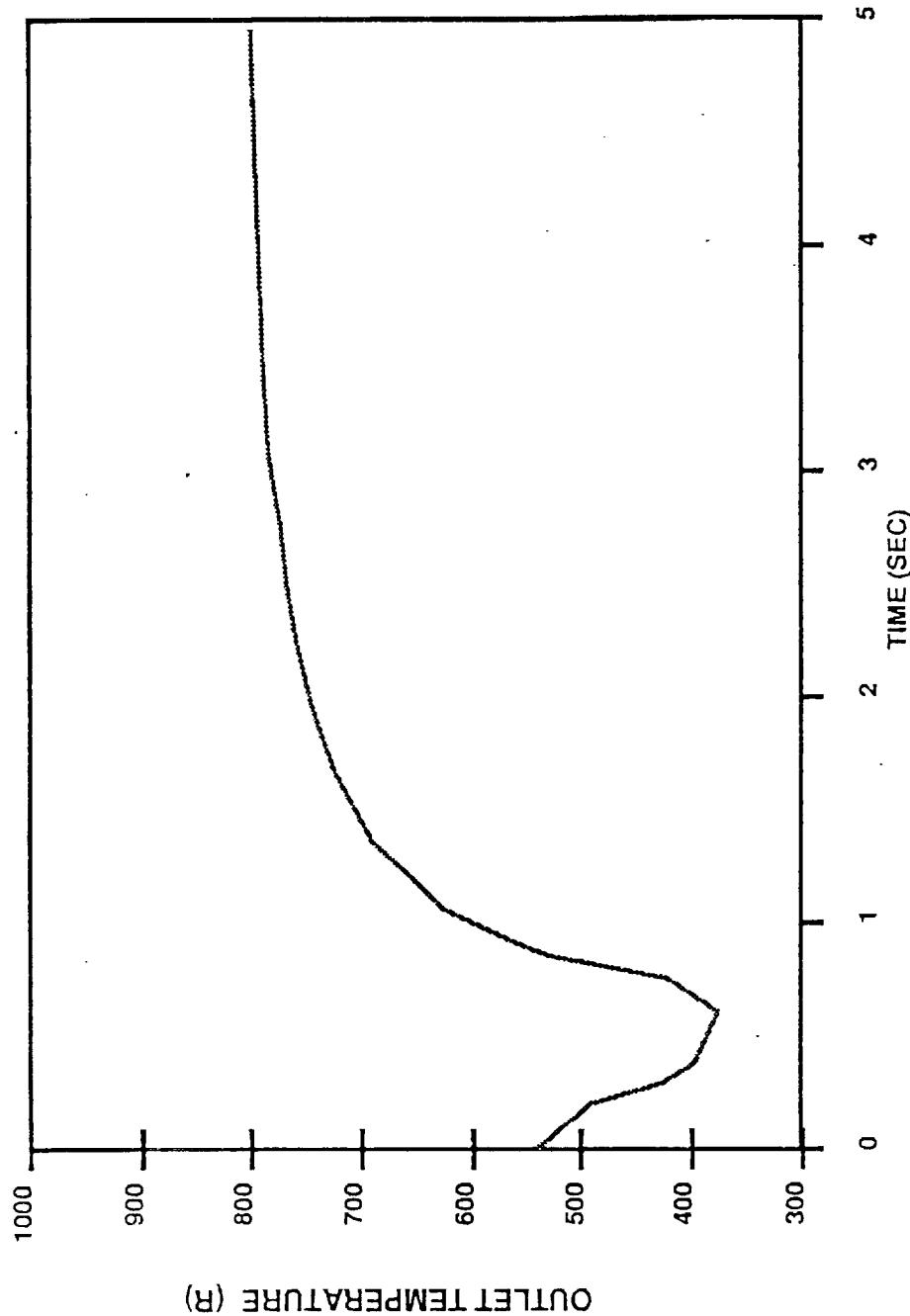
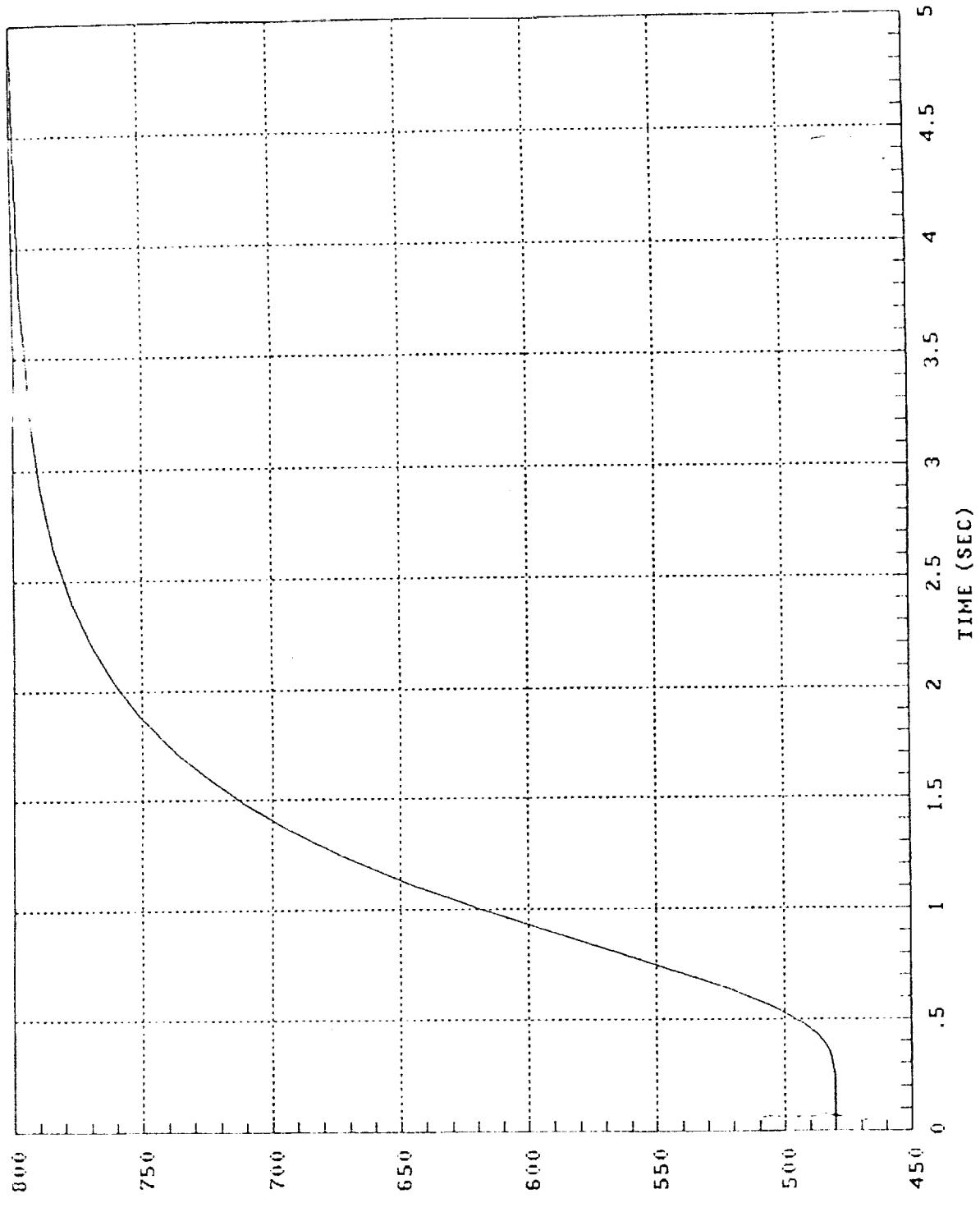


FIGURE 3



SYSTEM 4n-2 CATALYST BED TEMP---FIGURE 4

If the flow rate is sonic

$$\dot{w} = A P_{in} \sqrt{\frac{\gamma g}{RT} \left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma+1}{\gamma-1}}}$$

else

$$\dot{w} = A P_{in} \sqrt{\frac{g}{RT} \frac{2\gamma}{\gamma-1} \left[1 - \left(\frac{P_{out}}{P_{in}} \right)^{\frac{\gamma-1}{\gamma}} \right]}$$

$$A = A_0 + k_a t$$

Steam and He Tanks

The ΔP between the H_2O and He tanks will set the flow rate between the tanks. This will be simulated as an incompressible flow, with the pressure drop occurring at the valve with the outlet into the He tank.

The state variables used will be total energy of the contents of the tank and the mass.

E	BTU
M	lb _m

The mass flow out will be at an energy level of saturated liquid.

$$\frac{E}{M} = h \quad \frac{BTU}{lb}$$

$$\frac{V}{M} = v \quad \frac{ft^3}{lb}$$

The intersection of the v and h lines will give pressure and thus h_{sl} and h_{sv} .

Parameters needed for water.

$$h_{sl} \quad P \quad T \quad h_{sv} \quad v \quad \text{or} \quad \rho$$

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Initial Condition for Steam

$$\begin{aligned}v &= 0.034310 \text{ ft}^3/\text{lb} \\h &= 802.5 \text{ BTU/lb}\end{aligned}$$

As the liquid is extracted from the tank, the enthalpy drifts across the dome toward the saturated vapor boundary. When the tank enthalpy is:

$$h_t >= 0.1h_{sl} + 0.9h_{sv}$$

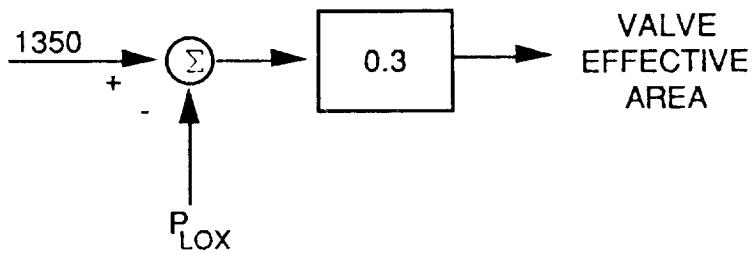
the enthalpy exiting the tank becomes:

$$h_{exit} = h_{sl} + (h_{sv} - h_{sl}) \left[\frac{h_t - h_{sl}}{h_{sv} - h_{sl}} - 0.9 \right] 10$$

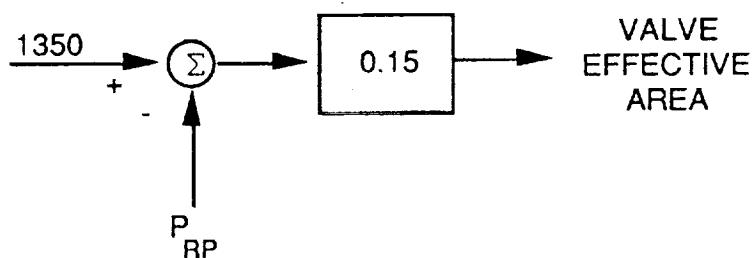
Control Designs

The pressure regulators on the LOX and RP tanks were modeled as simple proportional regulators. If the major pressure drop has to move from the tank to upstream of the primary heat source, an integral control will have to be used (minor impact to control system design).

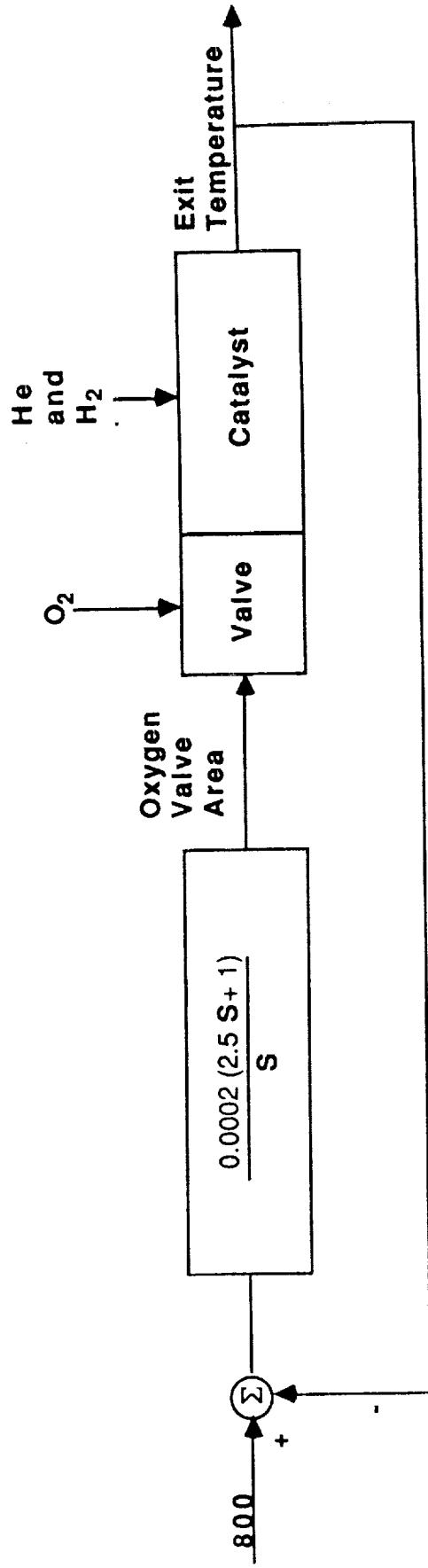
LOX Tank



RP Tank



Primary Heater Control (Catalyst)



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SYSTEM 4 Z

This system (Figure 5) uses gaseous Helium to pressurize a small LOX and liquid hydrogen tanks. The simulation assumes that the liquid hydrogen and oxygen tanks are pressurized to 400 psi above the super critical helium tank. The simulation has a source of liquid hydrogen and liquid oxygen at 400 psi above the super critical helium tank, but the amount of LOX and H₂ used is not measured. The O/F ratio of the secondary heater is accomplished by calibrated orifices in the hydrogen and oxygen lines. The flow is constant throughout the mission, being maintained by the constant delta pressure.

The primary heater has a temperature control to maintain the temperature of the helium exiting the heater to 1000 R.

The pressure regulators on the Oxidizer and fuel tanks are simple proportional controls, although this will have to be upgraded if the primary pressure drop does not occur at the fuel and oxidizer tank.

Model Development Configuration 4Z - LH₂ / LO₂ / He Heater

The system shown is figure 5. The components which were simulated and the associated controls are described in the following text.

LH₂/LO₂/He Heater

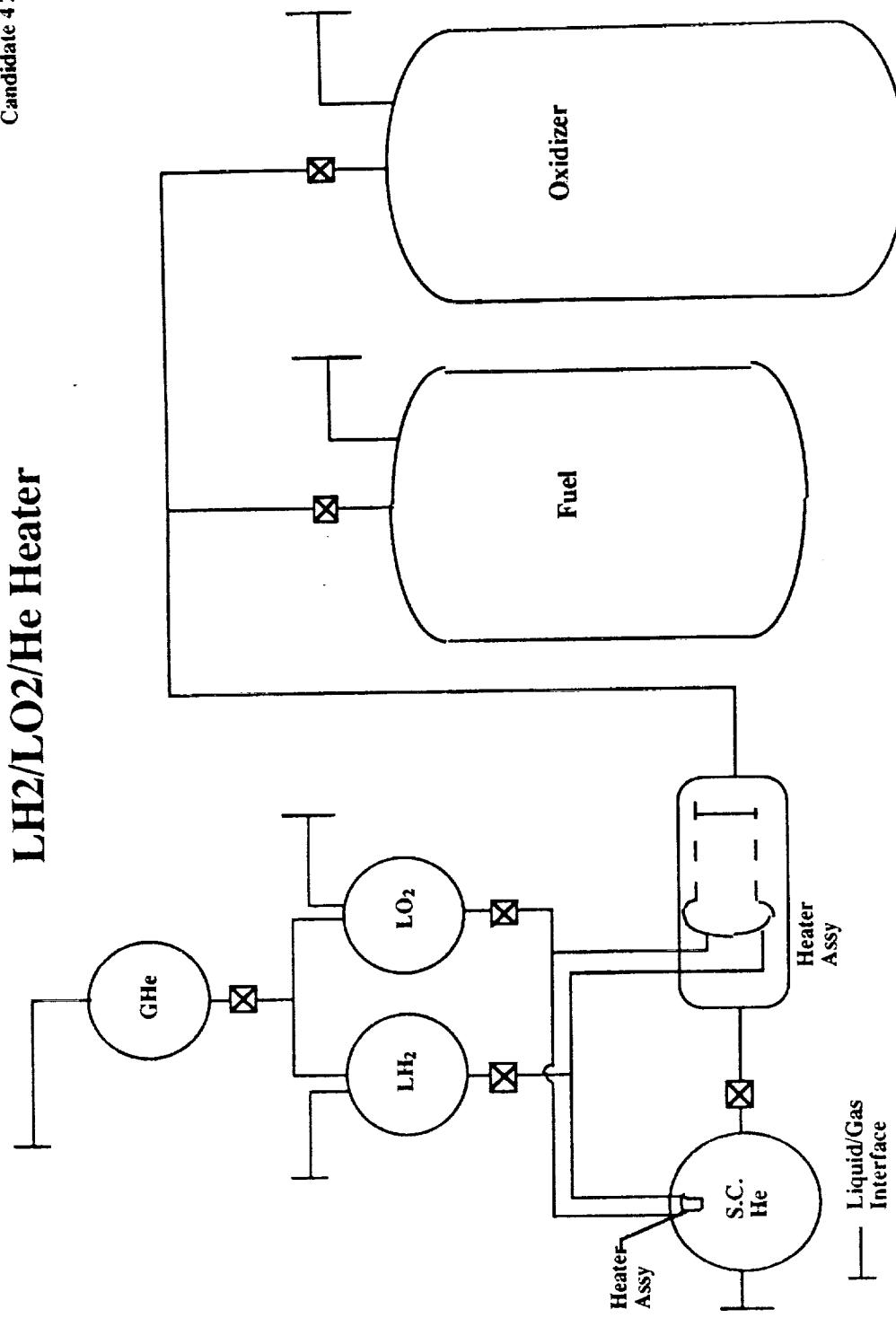


Figure 5

Secondary Heater for the He Tank

The LOX tank and LH₂ tank are pressurized from a gaseous H_c tank source. The pressure maintained in the supply tanks is maintained at 400 psi above the super critical H_e tank. This maintains a constant pressure across the flow orifice controlling the flow rate.

For 400 psi across the flow orifices the effective areas for the secondary heater are:

$$A_{LOX} = 0.02649 \text{ in}^2$$

$$A_{LH_2} = 0.009983 \text{ in}^2$$

Both the LOX and LH₂ are maintained at the same pressure. This is to maintain O/F ratio in the heater.

Flow Equations

$$\dot{w} = A \sqrt{\rho g \Delta P}$$

\dot{w} = mass flow of the fluid ~ lb_{in}/sec

A = effective area of the restriction ~ in²

ρ = density of the fluid ~ lb_{in}/in³

g = gravitational constraint ~ in/sec²

ΔP = pressure difference across the orifice ~ $\frac{\text{lb}_f}{\text{in}^2}$

$$\rho_{LOX} = 0.32843 \frac{\text{lb}}{\text{in}^3}$$

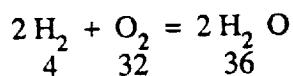
$$g = 32.17 * 12 = 386.04 \text{ in/sec}^2$$

$$\Delta P = 400 \text{ psi}$$

$$\dot{w}_{O_2} = A_{O_2} 3.560 \sqrt{\Delta P}$$

$$\dot{w}_{H_2} = A_{H_2} 1.181 \sqrt{\Delta P}$$

O/F ratio for stoichiometric



$$O/F = \frac{32}{4} = 8$$

$$\frac{O}{F} = \frac{A_{O_2} 3.560 \sqrt{\Delta P}}{A_{H_2} 1.181 \sqrt{\Delta P}} = 7.9978$$

Thus

$$\dot{w}_{H_2 O} = 1.125 \dot{w}_{O_2}$$

the excess of H_2 is ignored.

The total flow of LOX and LH₂ are not determined since they do not effect the control of the system.

Volumetric Flow Rate of the LOX and RP Tanks

Main tank volumetric flow rates:

$$\left. \begin{array}{l} LOX = 112.4 \text{ ft}^3/\text{sec} \\ RP = 65.9 \text{ ft}^3/\text{sec} \end{array} \right\} 0 < t < 30 \text{ sec}$$

$$\left. \begin{array}{l} \text{LOX} = 84.0 \text{ ft}^3/\text{sec} \\ \text{RP} = 49.4 \text{ ft}^3/\text{sec} \end{array} \right\} 30 < t < 120 \text{ sec}$$

The flow rates were increased by 20% to account for heat transfer to the LOX and RP tanks. These data became the derivatives for the tank ullage state variables.

The H_c pressure in both tanks is considered to be an ideal gas.

$$PV = MRT$$

$$P = \frac{MRT}{V}$$

$$R = \frac{1545}{4.0026} \quad \frac{\text{ft lb}_f}{\text{lb}_m \text{ °R}}$$

$$P \frac{\text{lb}_f}{\text{in}^2} = \frac{M \text{ lb}_m R \frac{\text{ft lb}_f}{\text{lb}_m \text{ °R}} T \text{ °R}}{V \text{ ft}^3} \quad \frac{\text{ft}^2}{144 \text{ in}^2}$$

Pressure Regulator Flow Rate

The pressure regulator flows are based on an ideal gas with an average molecular weight of 4.0026 and a gama of 1.655.

If the flow rate is sonic

$$\dot{w} = A P_{in} \sqrt{\frac{\gamma g}{RT} \left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma+1}{\gamma-1}}}$$

else

$$\dot{w} = A P_{in} \sqrt{\frac{g}{RT} \frac{2 \gamma}{\gamma - 1} \left[1 - \left(\frac{P_{out}}{P_{in}} \right)^{\frac{\gamma-1}{\gamma}} \right]}$$

The H_e flow into tanks are integrated to generate the H_e mass in the LOX tank ullage and RP tank ullage. (This is used to calculate the pressure in the tanks.) The sum of the flows is the negative derivative of the H_e tank mass.

H_e Tank

The energy released into the H_e tank is the change in enthalpy in the steam flow times the flow rate.

$$Q = (h_{\text{steam}} + h_{\text{fusion}} - h_{\text{ice}}) \dot{w}_{H_2O}$$

h_{steam} is the enthalpy of the steam generated in the secondary heater, with the reference being $0.0 \frac{\text{BTU}}{\text{lb}_m}$ at 32.0°F and 14.7 psi and the water in liquid state.

h_{fusion} is the energy released to freeze the water.
(144 BTU/lb)

h_{ice} is the enthalpy of ice at temperature less than 32.0°F . $h_{\text{ice}}(T)$

The temperature derivative is

$$\dot{T} = \frac{Q}{MC_p}$$

\dot{T} is the rate of change of temperature of the H_e in the tank.

Q is the heat released from the steam.

M is the mass of the H_e in the tank.

C_p is the specific heat of the H_e in the tank.

The specific heat is a function of the H_e temperature and is obtained from a lookup table.

LOX and RP Ullage Temperature

The temperature of the helium in the ullage is calculated the same as the helium tank.

$$\dot{T} = \frac{Q}{MC_p}$$

where

$$Q = \dot{w}_{in} C_p (T_{in} - T_{tank})$$

but

$$\dot{w}_{in} = \dot{M}_{tank}$$

$$\dot{T}_{tank} = \frac{\dot{w} C_p (T_{in} - T_{tank})}{M C_p}$$

$$\dot{T}_{tank} = (T_{in} - T_{tank}) \dot{M}/M$$

Primary Heater

The effective area ration of the LH₂ and LOX valves is kept to 0.3769 which yields an O/F ratio of 8 : 1. An 8 : 1 O/F ratio produces stoichiometric combustion.

The normal design point for the primary heater with the helium dilution is an outlet temperature of 1000°R. The assumed

enthalpy of the steam after combustion is 4500 $\frac{\text{BTU}}{\text{lb}}$.

$$\begin{aligned} \dot{w}_{H_2O} (4500 - h_{1000R}) + \dot{w}_{He} (h_{He_{in}} - h_{He_{1000R}}) \\ = (T_o - 1000) \dot{w} C_p \end{aligned}$$

where

$$\dot{w}C_p = \dot{w}_{H_2O} C_{p_{H_2O}} + \dot{w}_{He} C_{p_{He}}$$

$$C_{p_{He}} = 1.2400 \frac{\text{BTU}}{\text{lb}} R$$

$$C_{p_{H_2O}} = 0.8864 \frac{\text{BTU}}{\text{lb}} R$$

$$h_{H_2O} \underset{1000 \text{ psi}}{\underset{2000 \text{ psi}}{=}} 1474.1 \frac{\text{BTU}}{\text{lb}}$$

$$h_{He} \underset{1000 \text{ R}}{\underset{2000 \text{ psi}}{=}} 1267.0 \frac{\text{BTU}}{\text{lb}}$$

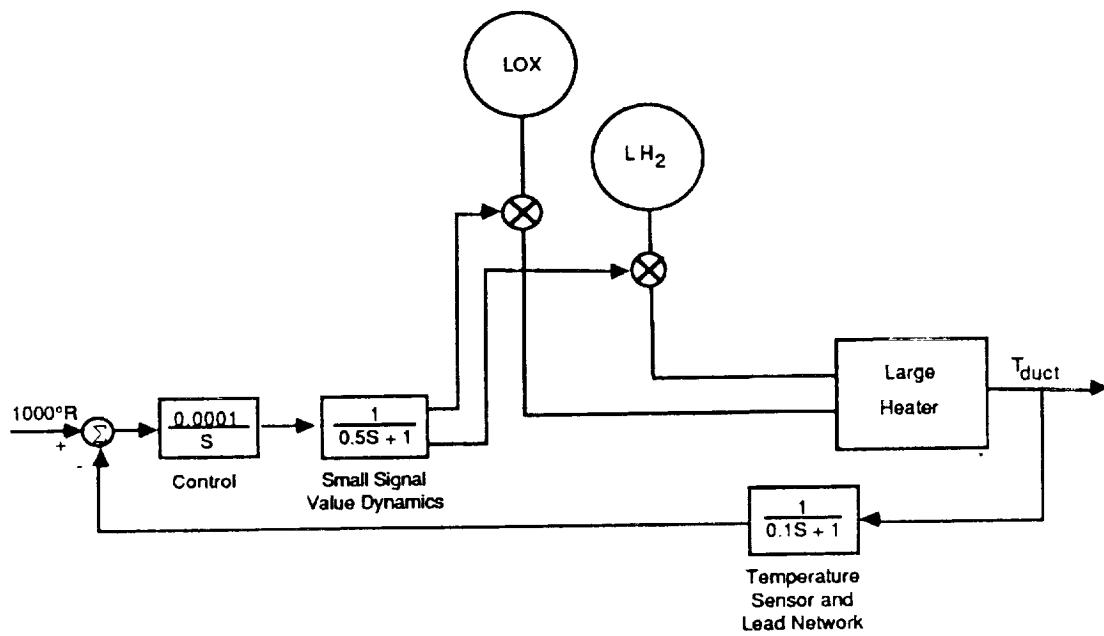
Thus

$$\begin{aligned} (T_O - 1000) \dot{w} C_p &= \dot{w}_{H_2O} (4500 - 1474.1) + \dot{w}_{He} (h_{He_{in}} - 1267.0) \\ T_O &= 1000 + \frac{3025.9 \dot{w}_{H_2O} + \dot{w}_{He} (h_{He_{in}} - 1267.0)}{\dot{w} C_p} \end{aligned}$$

where

$$\dot{w}_{H_2O} = 1.125 \dot{w}_{LOX}$$

The temperature sensor with a lead network incorporated is assumed to have a 10 rad/sec break frequency.

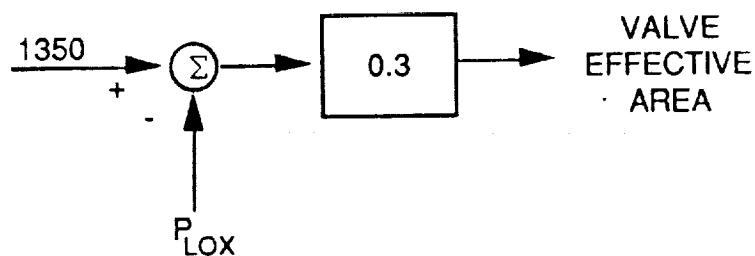


Primary Heater Control

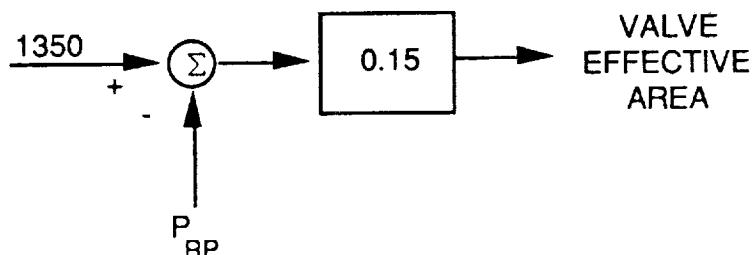
Pressure Regulator Design

The pressure regulators on the LOX and RP tanks were modeled as simple proportional regulators. If the major pressure drop has to move from the tank to upstream of the primary heat source, an integral control will have to be used (minor impact to control system design).

LOX Tank



RP Tank



SIMULATION RESULTS

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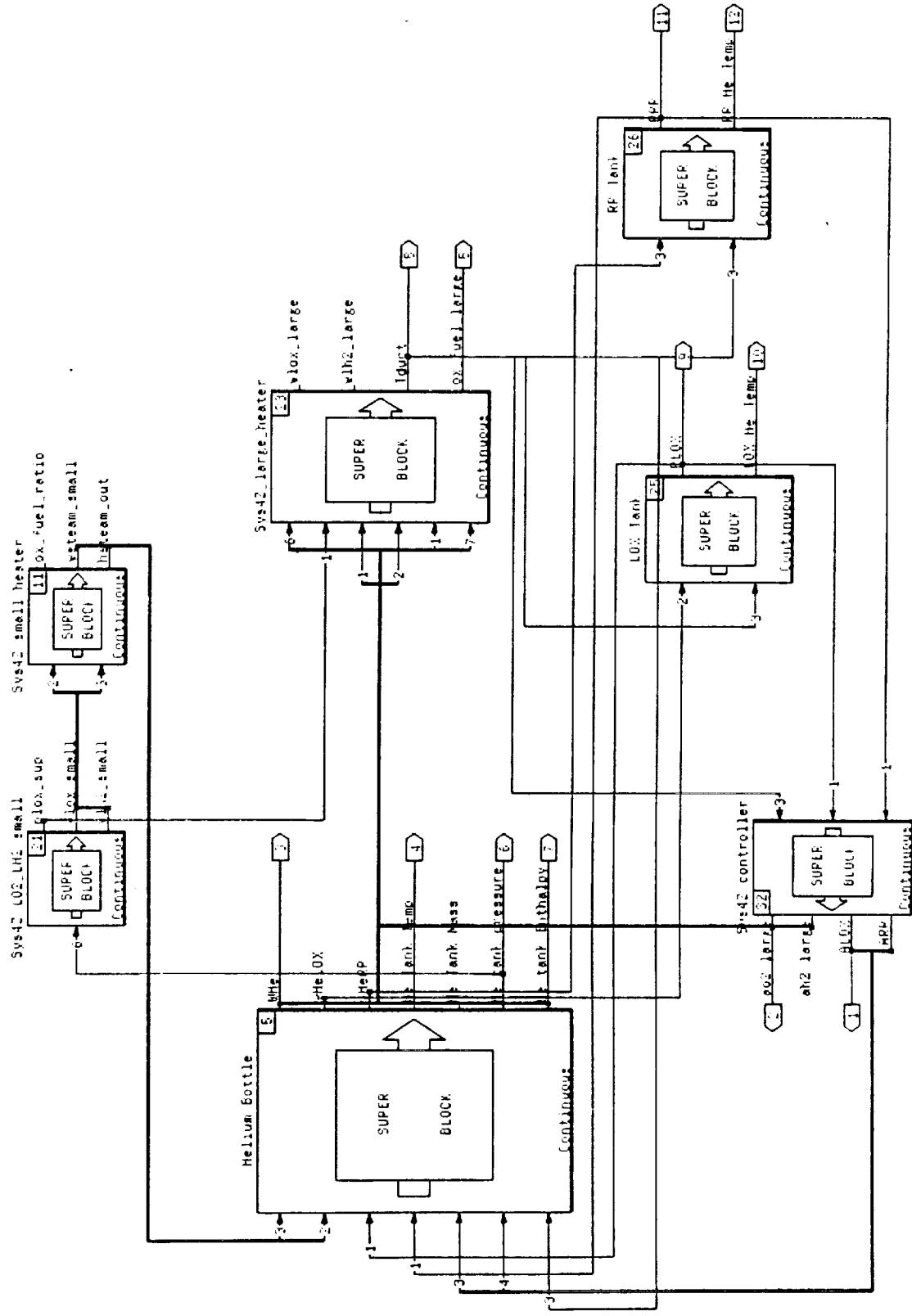
CONFIGURATION 4Z
LOX/LH₂ HEATER / LOX/LH₂ HEATER

MATRIX X BLOCK DIAGRAMS
MATRIX X PLOTS

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HINTS

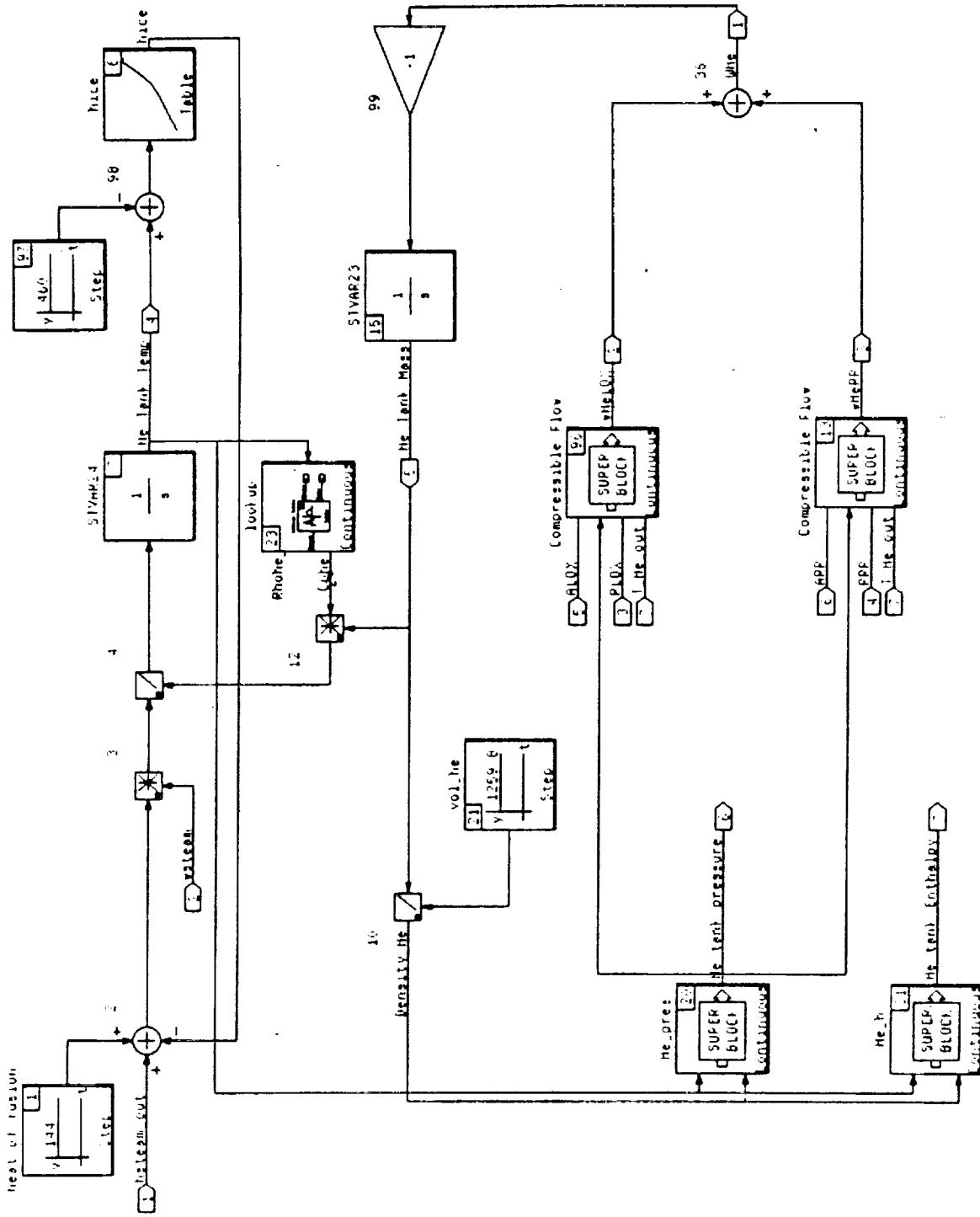
Continuous Super-Block
Configuration 4Z Ext. Inputs Ext. Outputs
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Continuous Super-Block Ext. Inputs Ext. Outputs
 Helium Bottle 7 7



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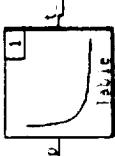
Continuous Super-Block
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Ext. Inputs Ext. Outputs

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$\rho_{1,0}$ vs Rho

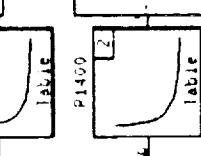
$\frac{1}{2}$



$\rho_{1,0}$ vs Rho

$\frac{1}{2}$

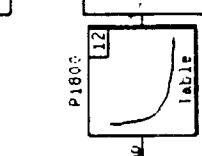
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$\rho_{1,0}$ vs Rho

$\frac{1}{2}$

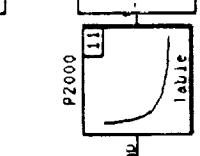
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$\rho_{1,0}$ vs Rho

$\frac{1}{2}$

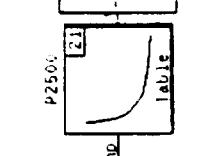
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$\rho_{1,0}$ vs Rho

$\frac{1}{2}$

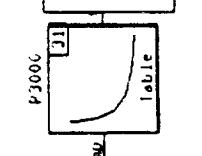
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$\rho_{1,0}$ vs Rho

$\frac{1}{2}$

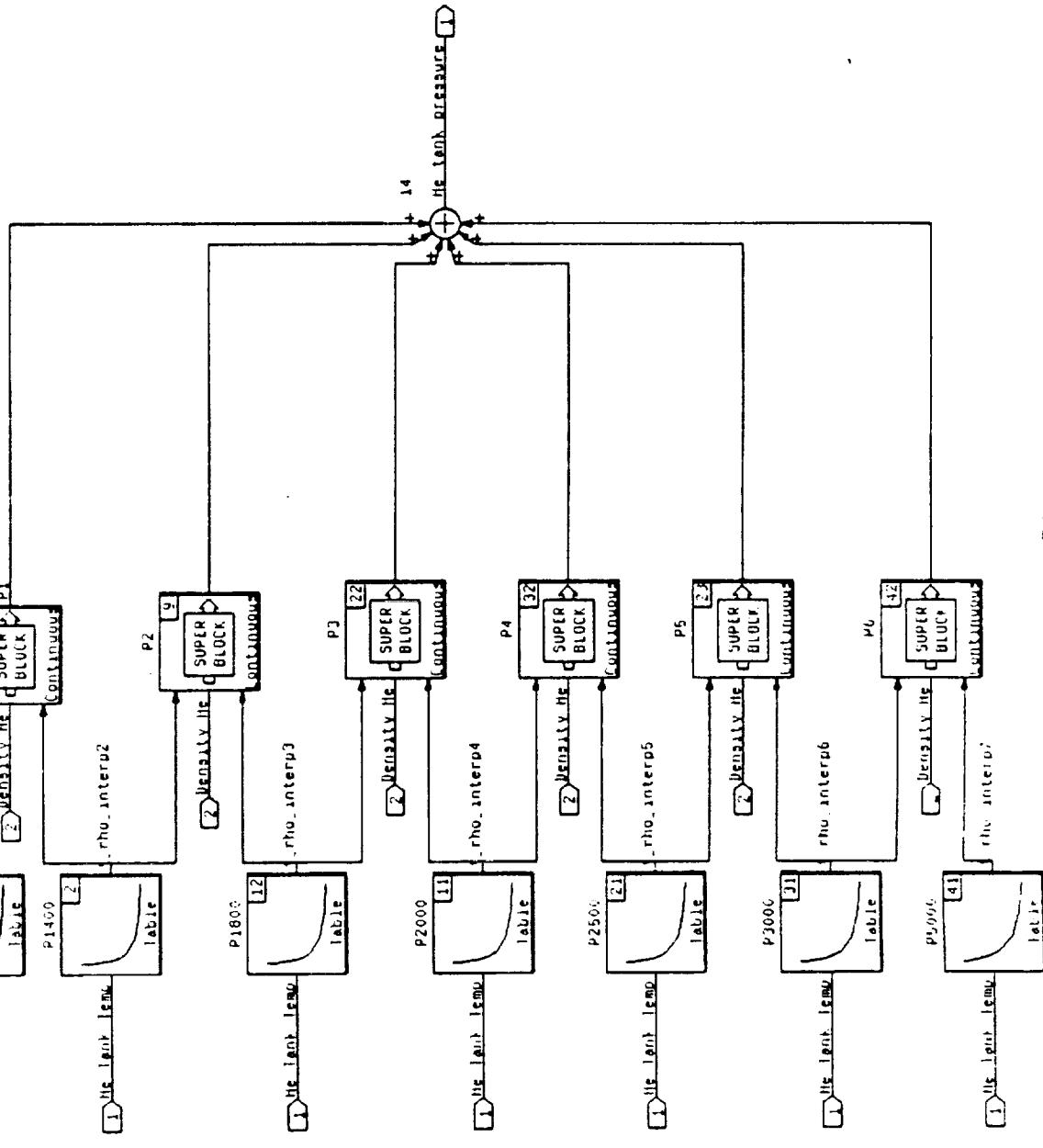
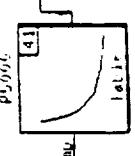
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$\rho_{1,0}$ vs Rho

$\frac{1}{2}$

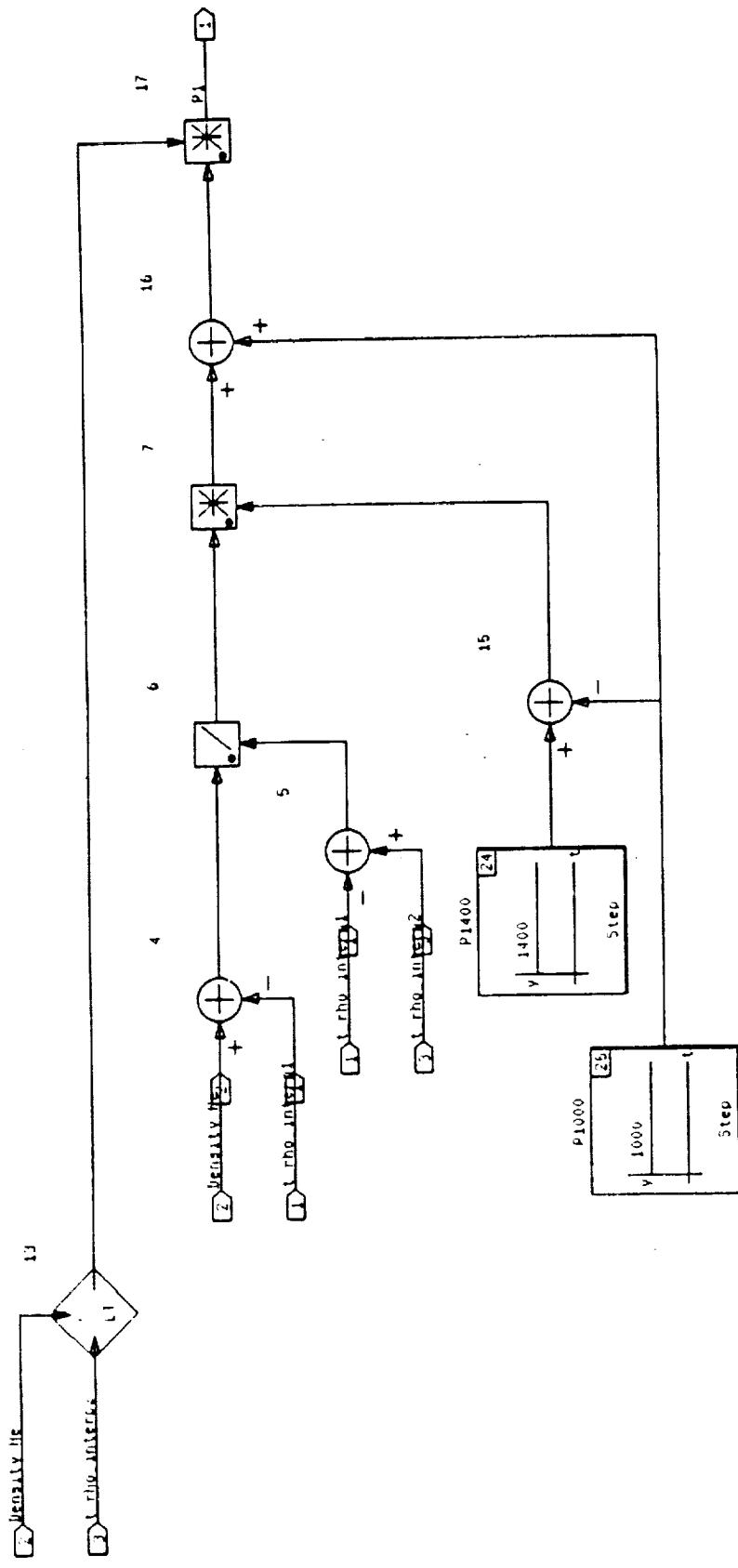
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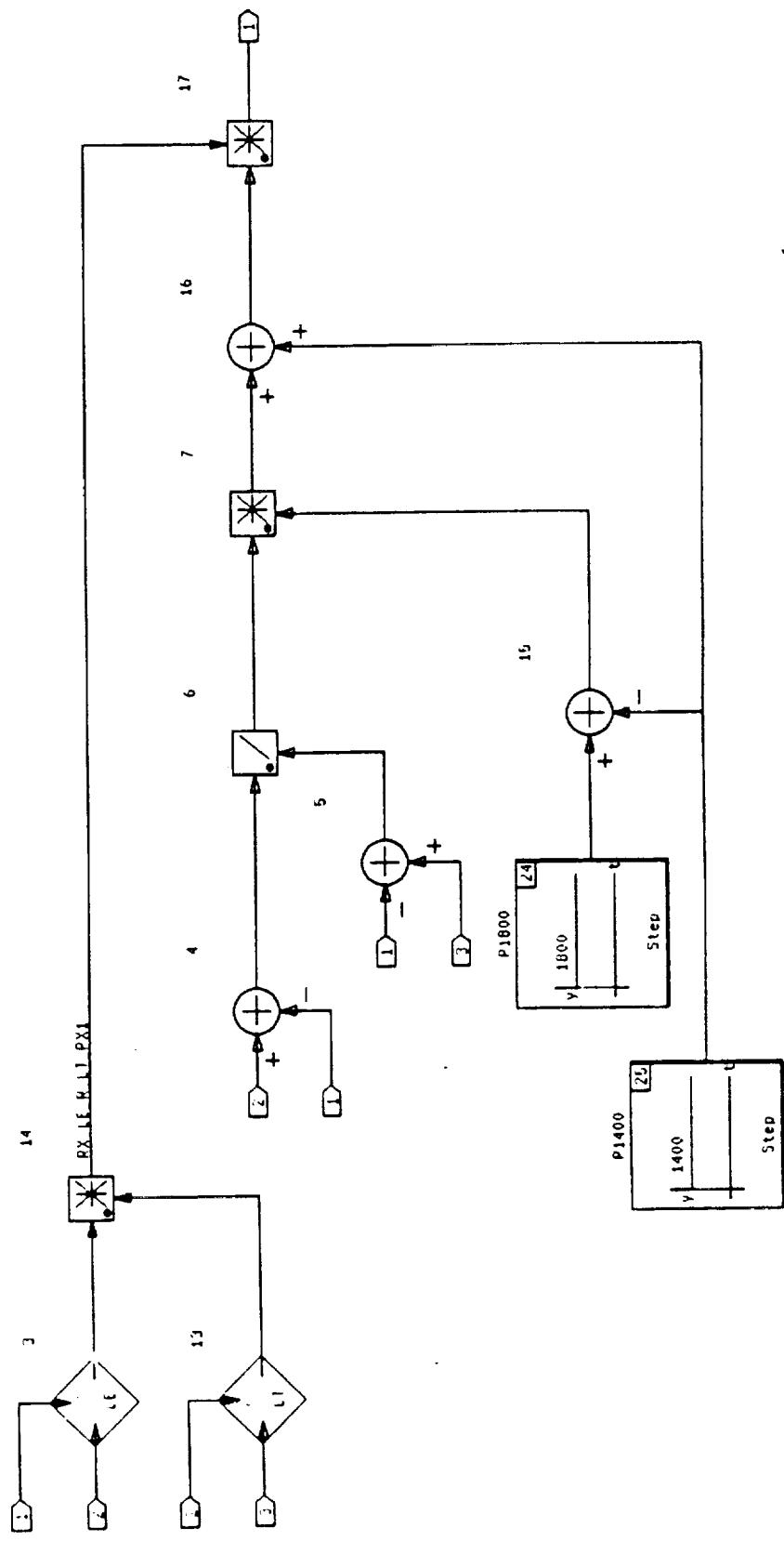
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
 P1 3 1



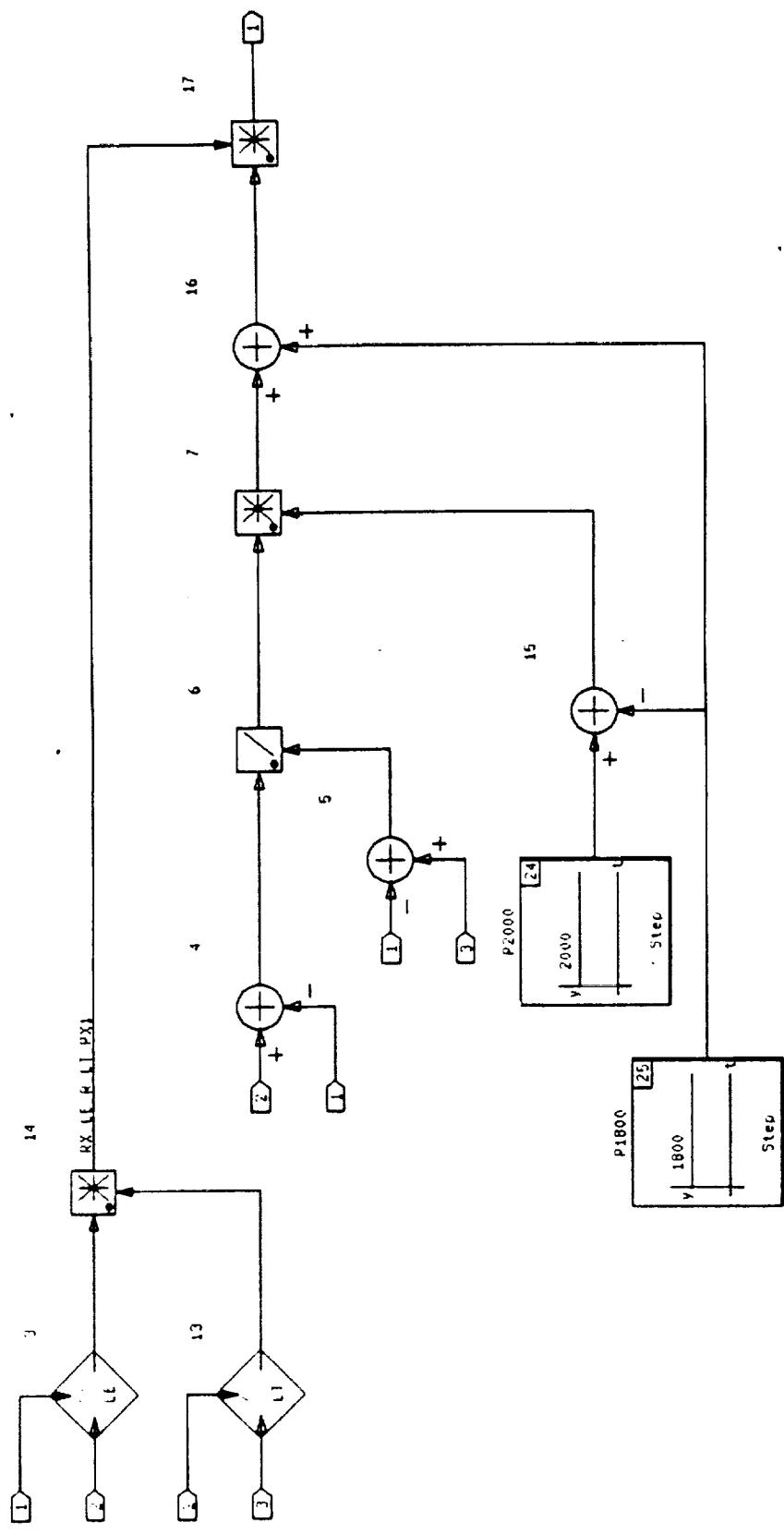
HINTS

Continuous Super-Block P2 Ext. Inputs 3 Ext. Outputs 1



HINTS

Continuous Super-Block P3 Ext. Inputs 3 Ext. Outputs 1



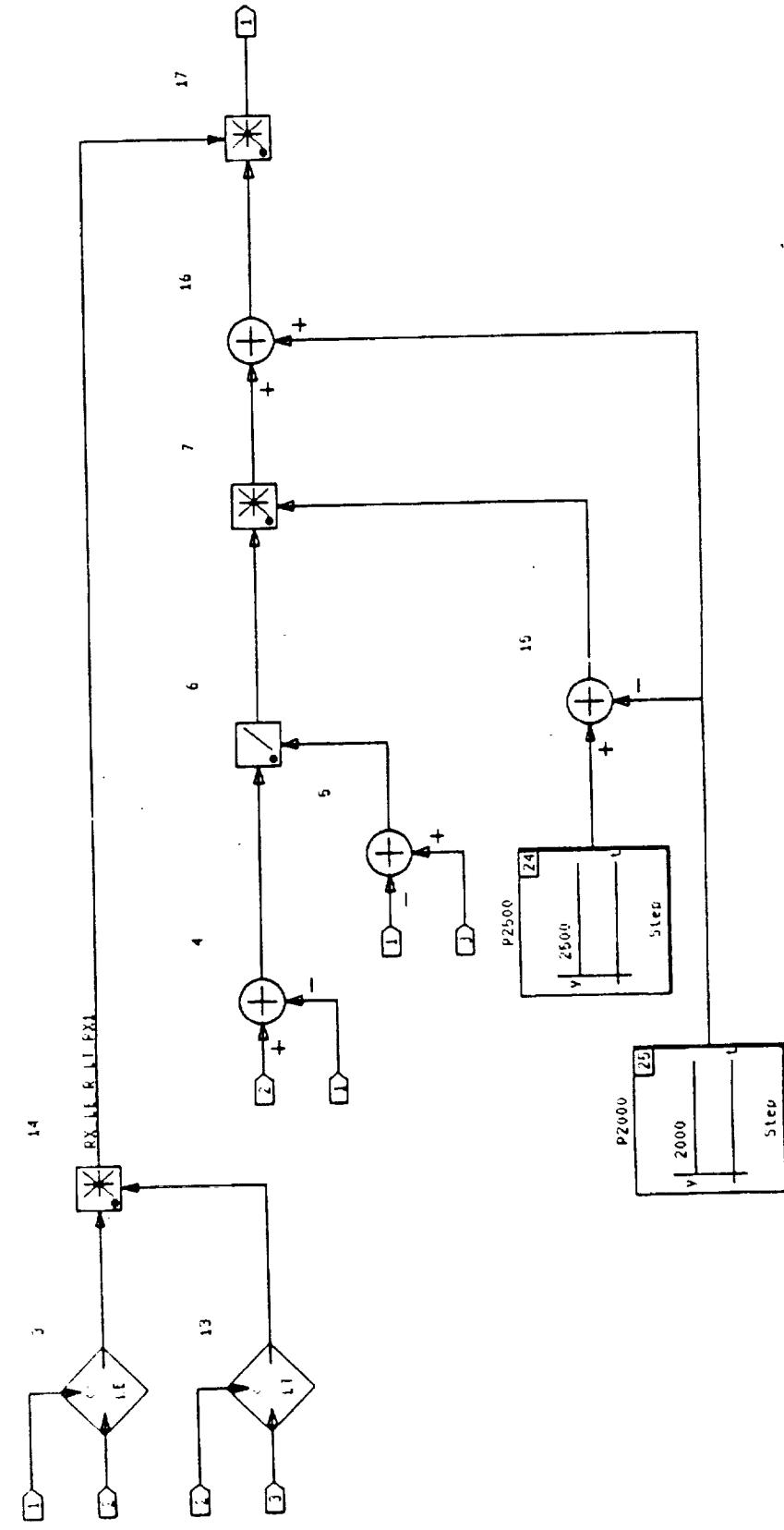
HINTS

Continuous Super-Block
P4

Ext. Inputs Ext. Outputs

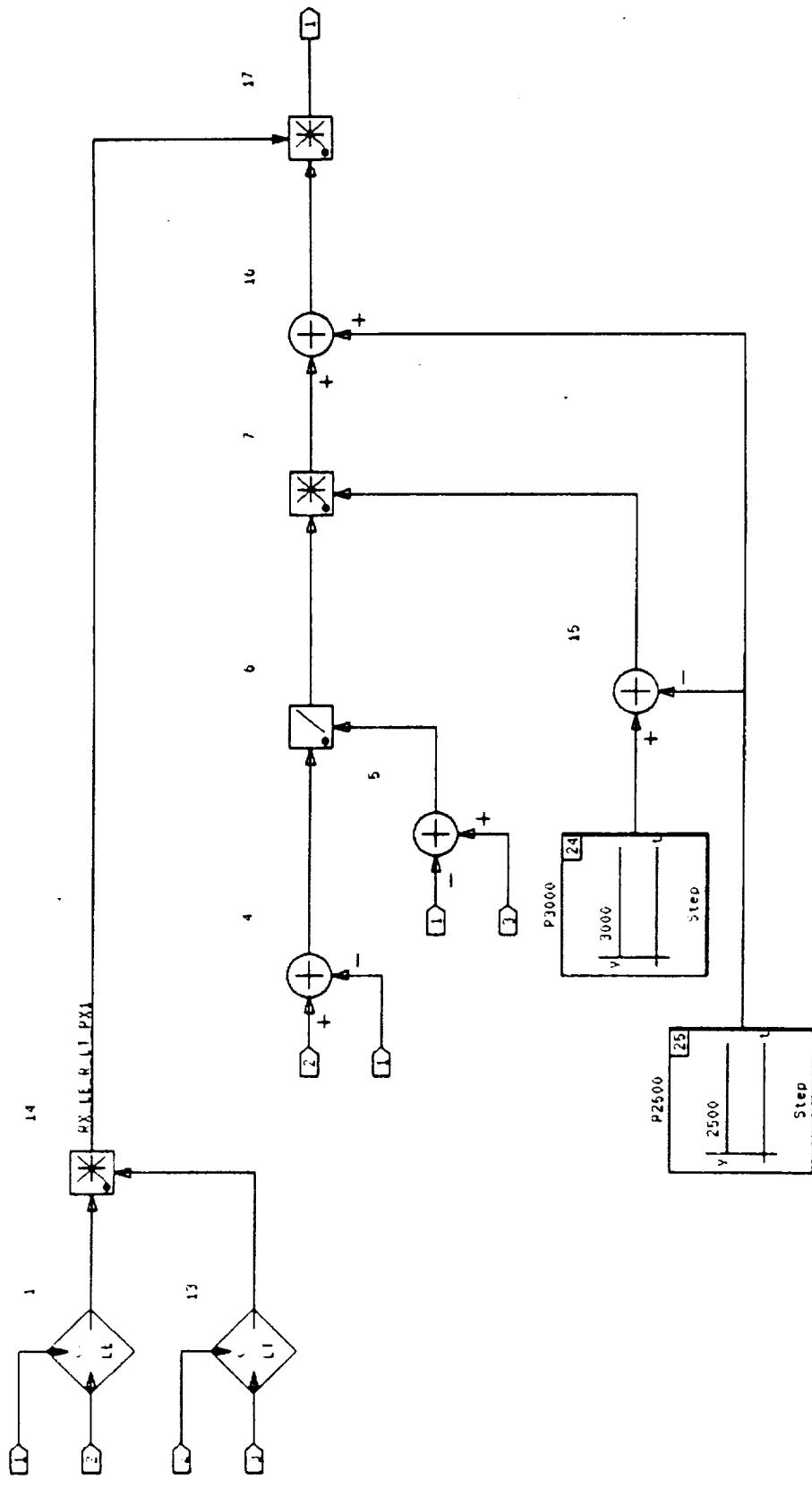
3

1



HINTS

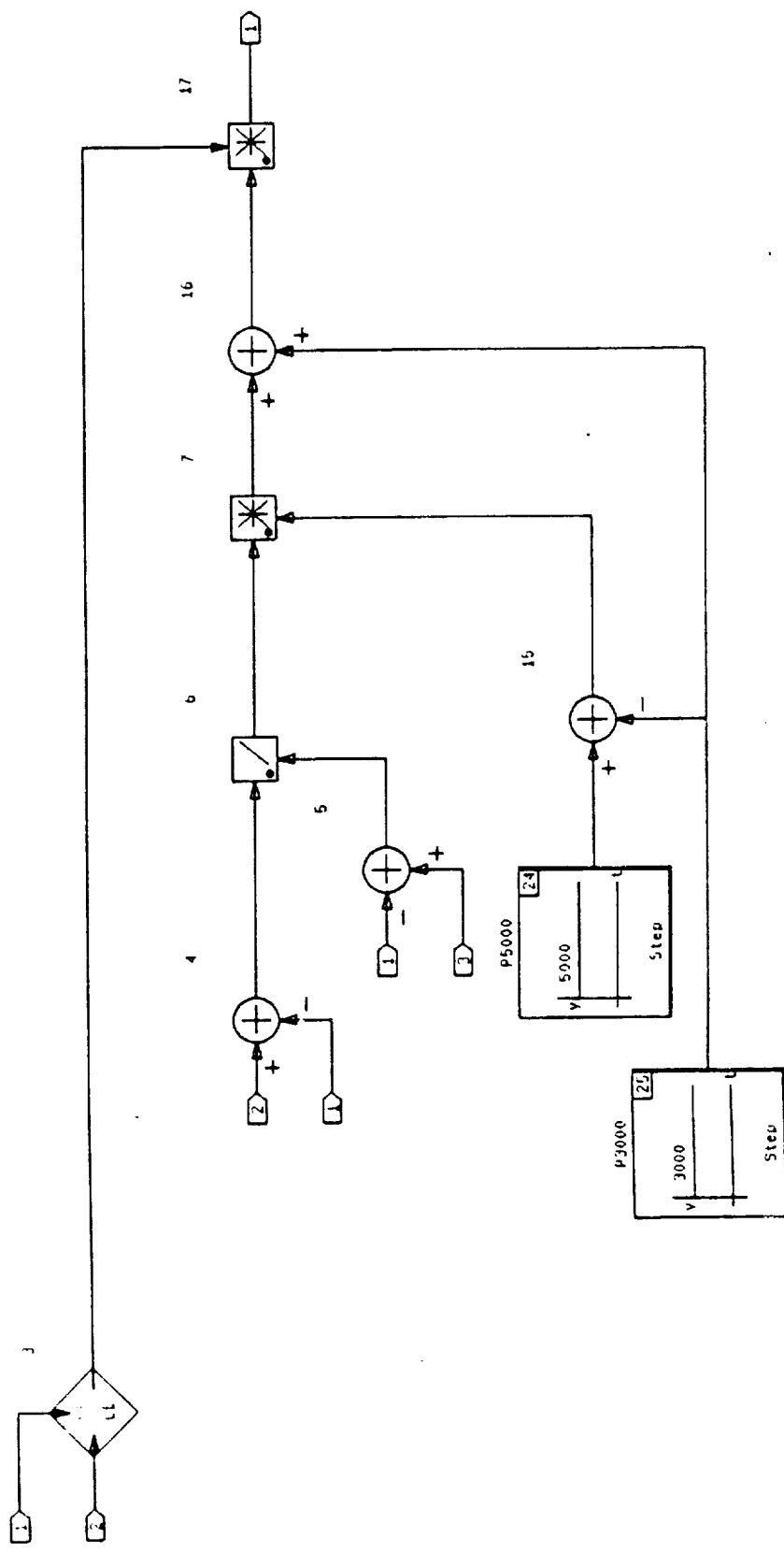
Continuous Super-Block
PS
Ext. Inputs Ext. Outputs
3 1



HINTS

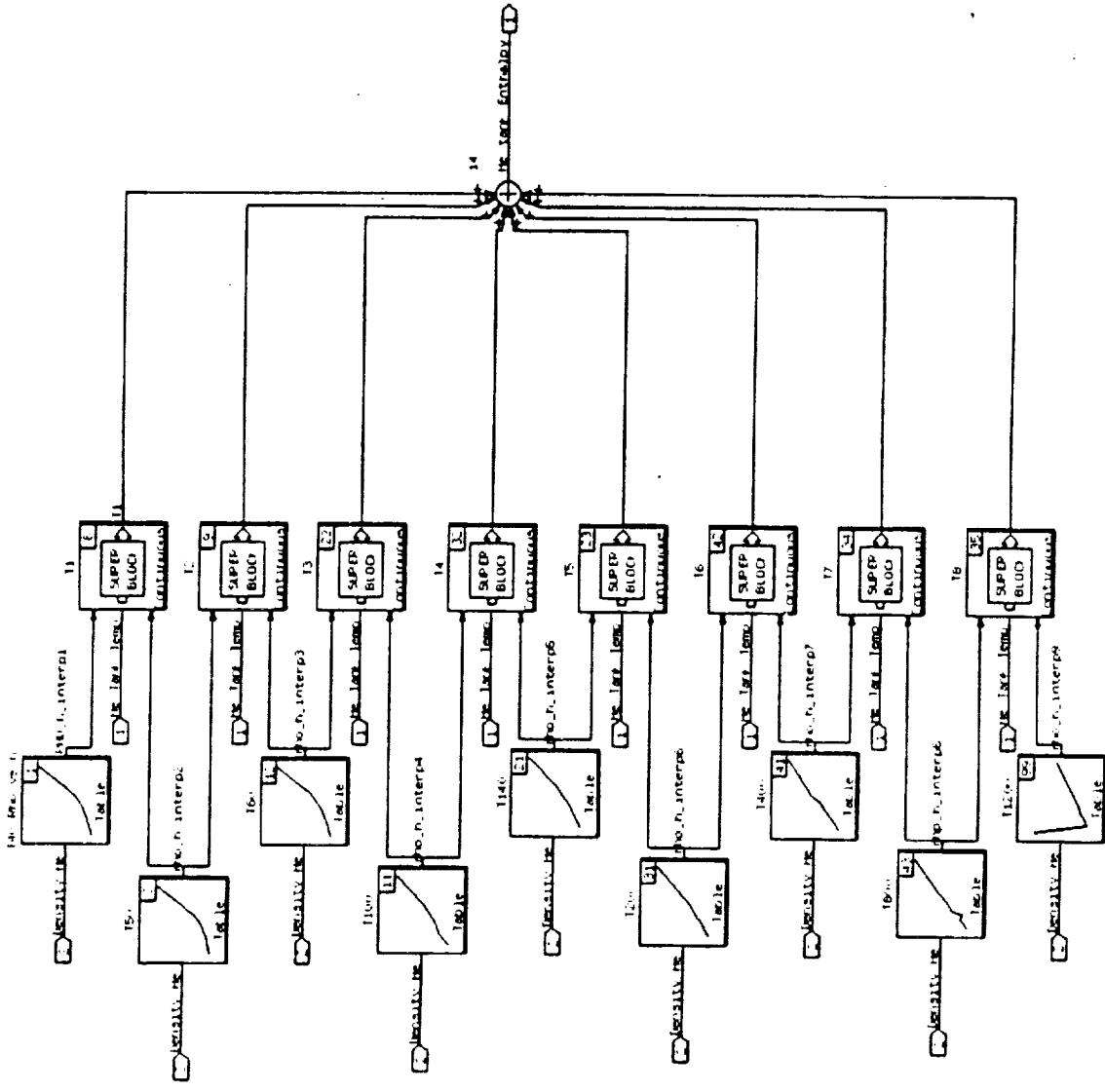
Continuous Super-Block
P6

Ext. Inputs Ext. Outputs
3 1



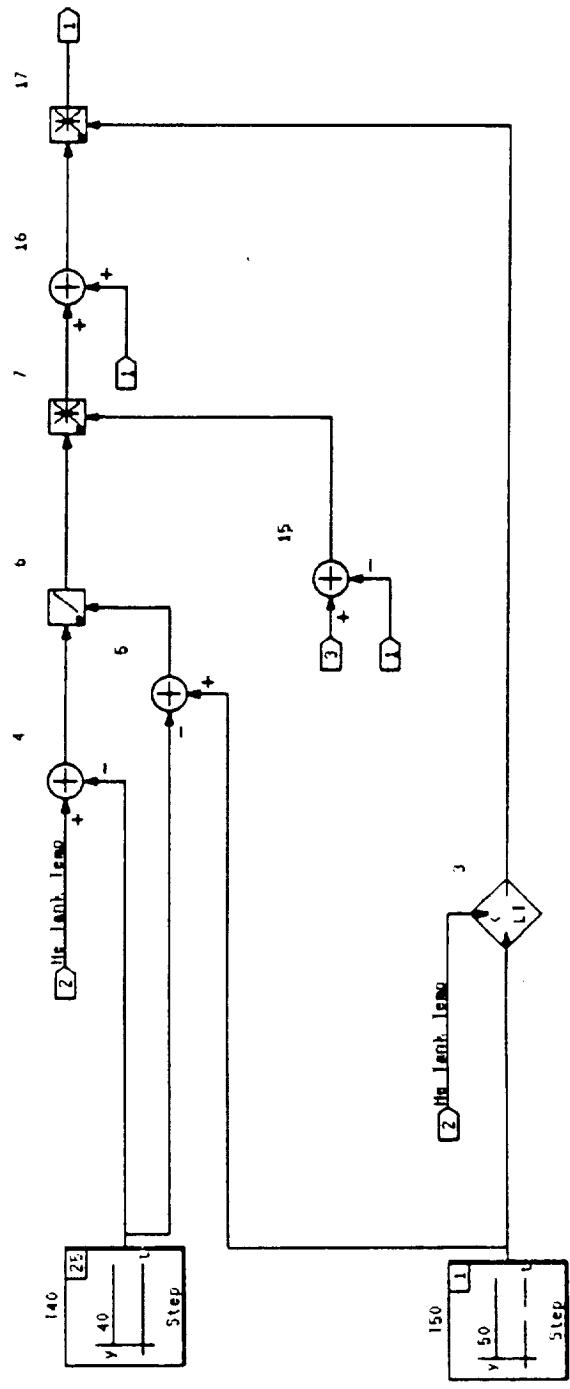
HINTS

Continuous Super-Block He_Hi



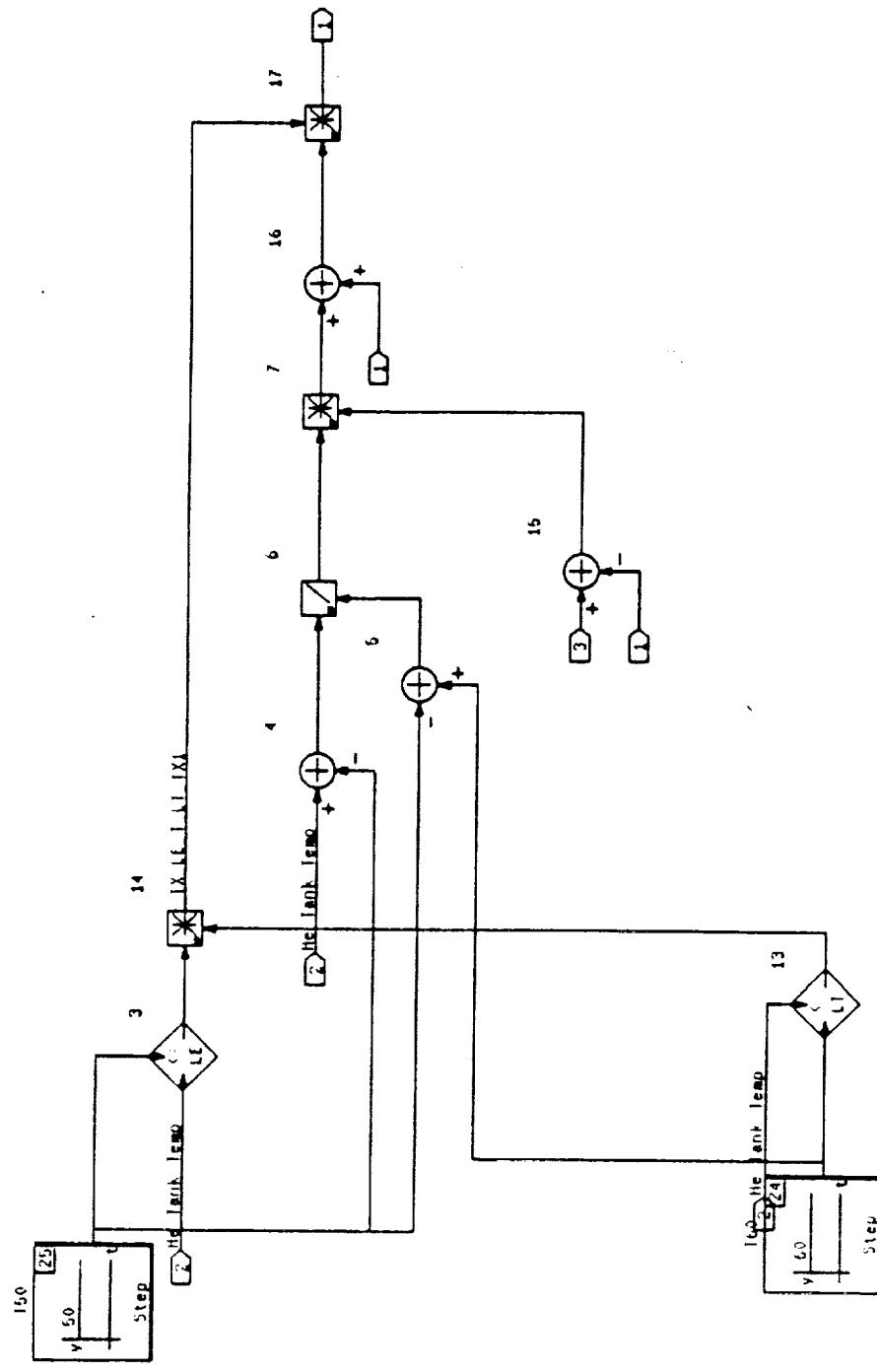
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
 T1 3 1



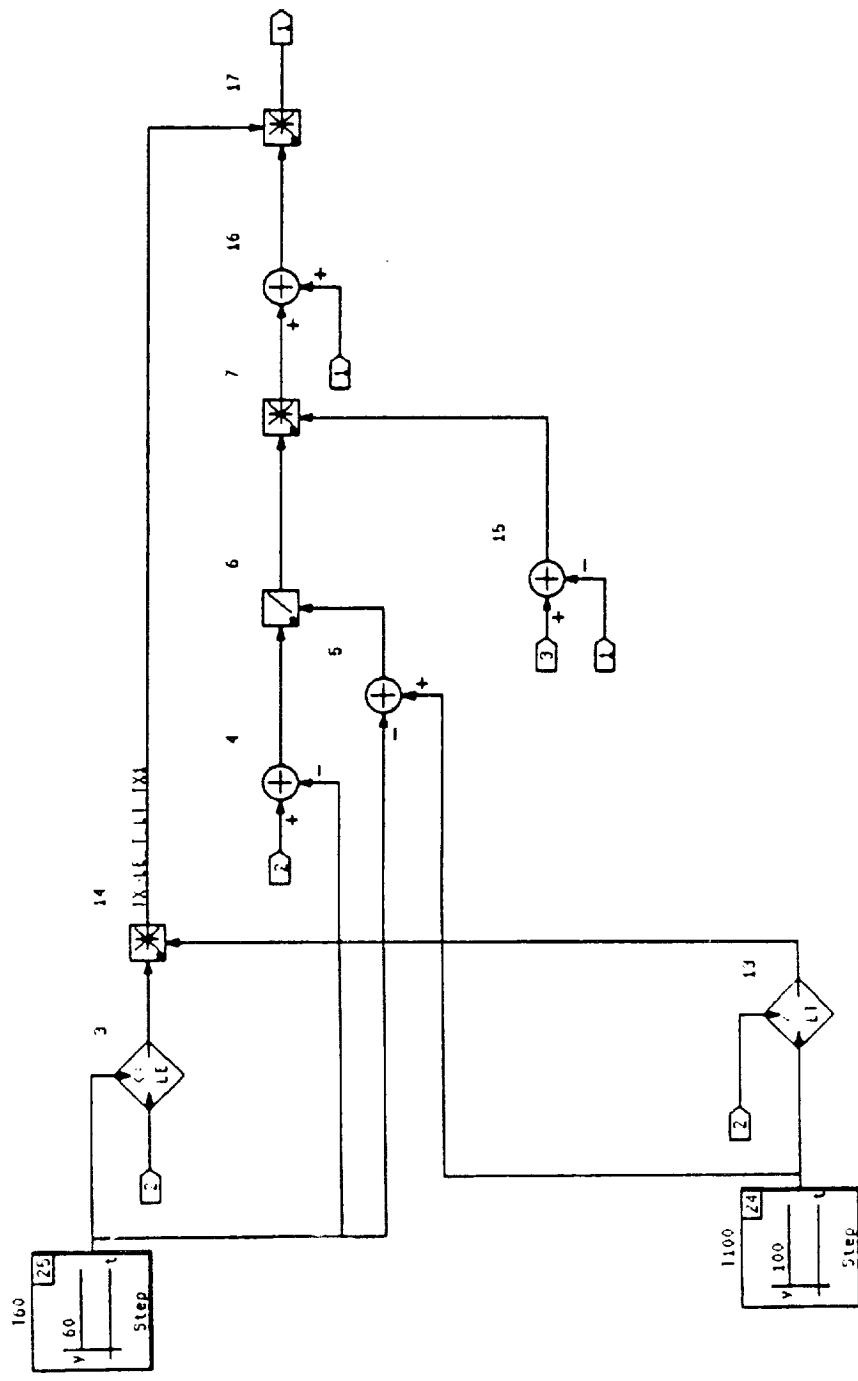
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
T12 3 1



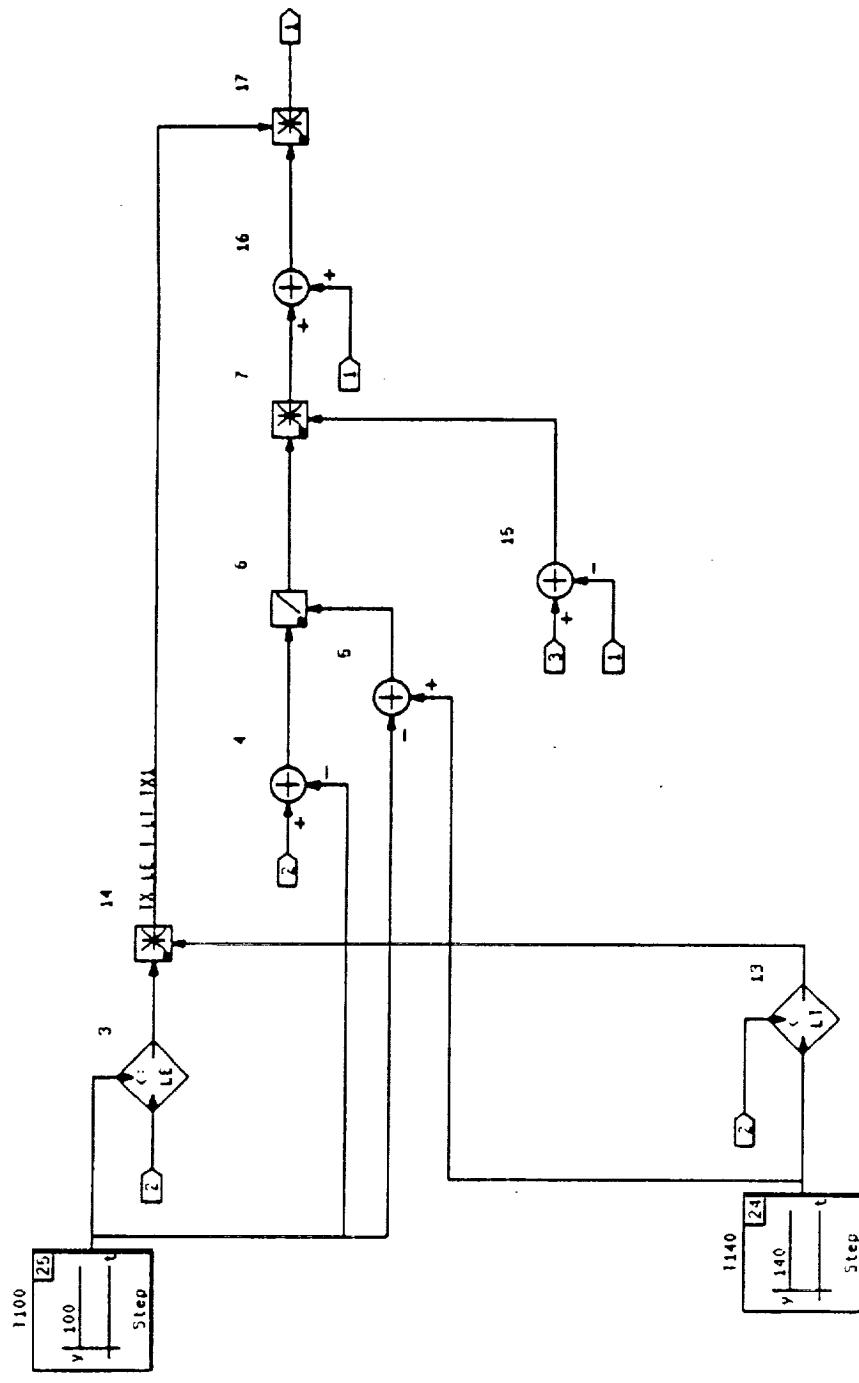
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
T3 3 1



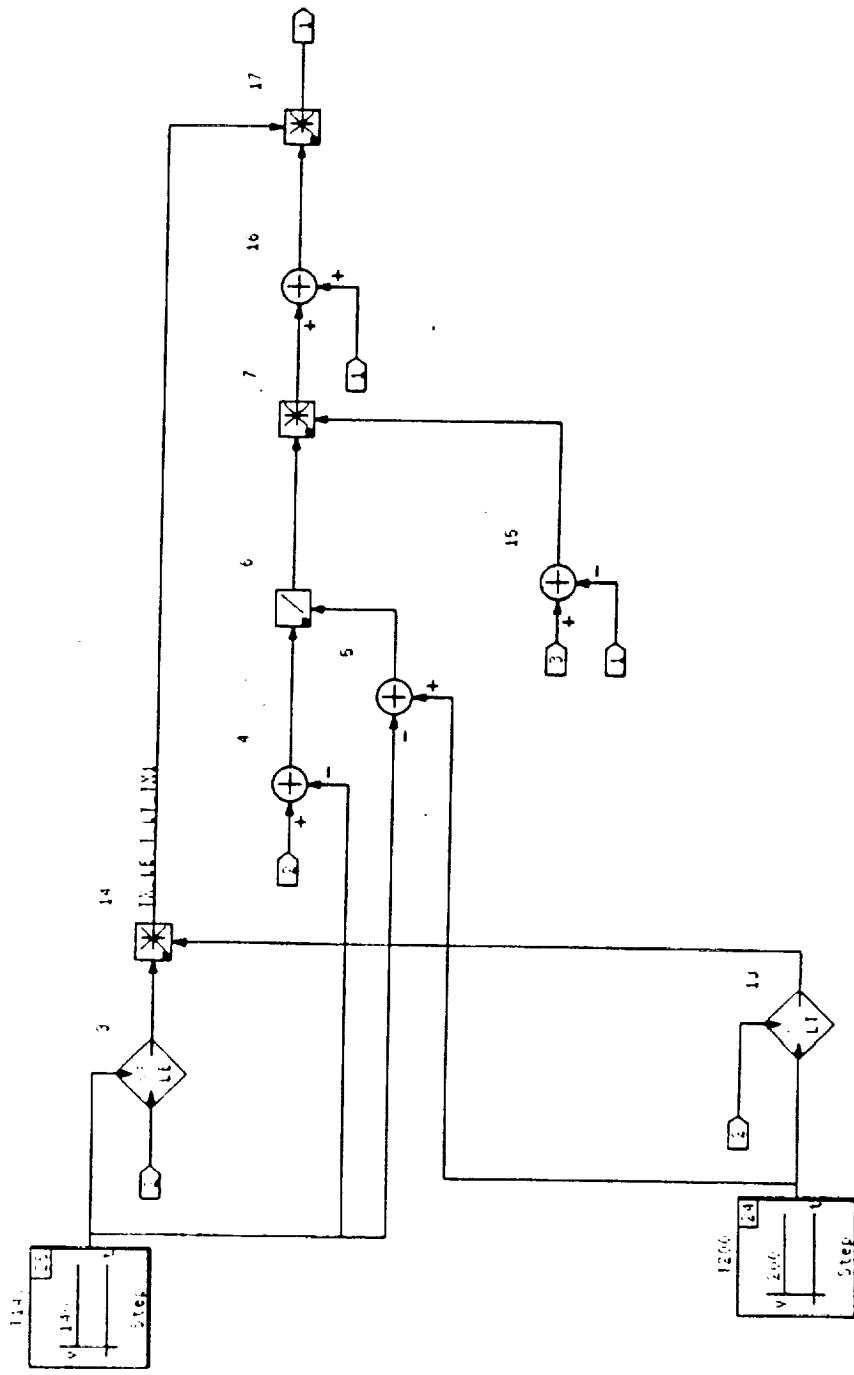
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
14 3 1



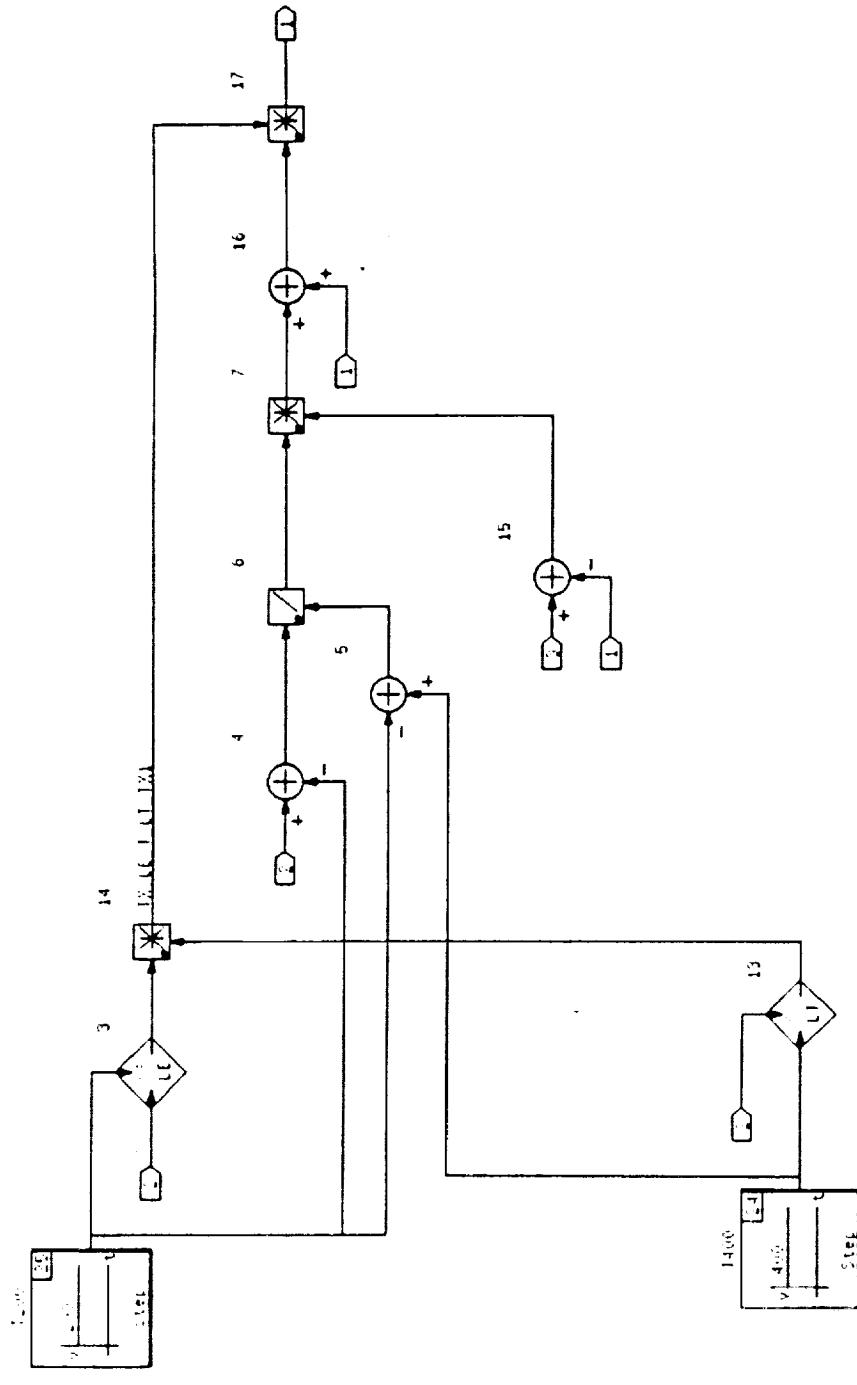
HINTS

Continuous Super-BLOCK
T5 Ext. Inputs Ext. Outputs
 3 1



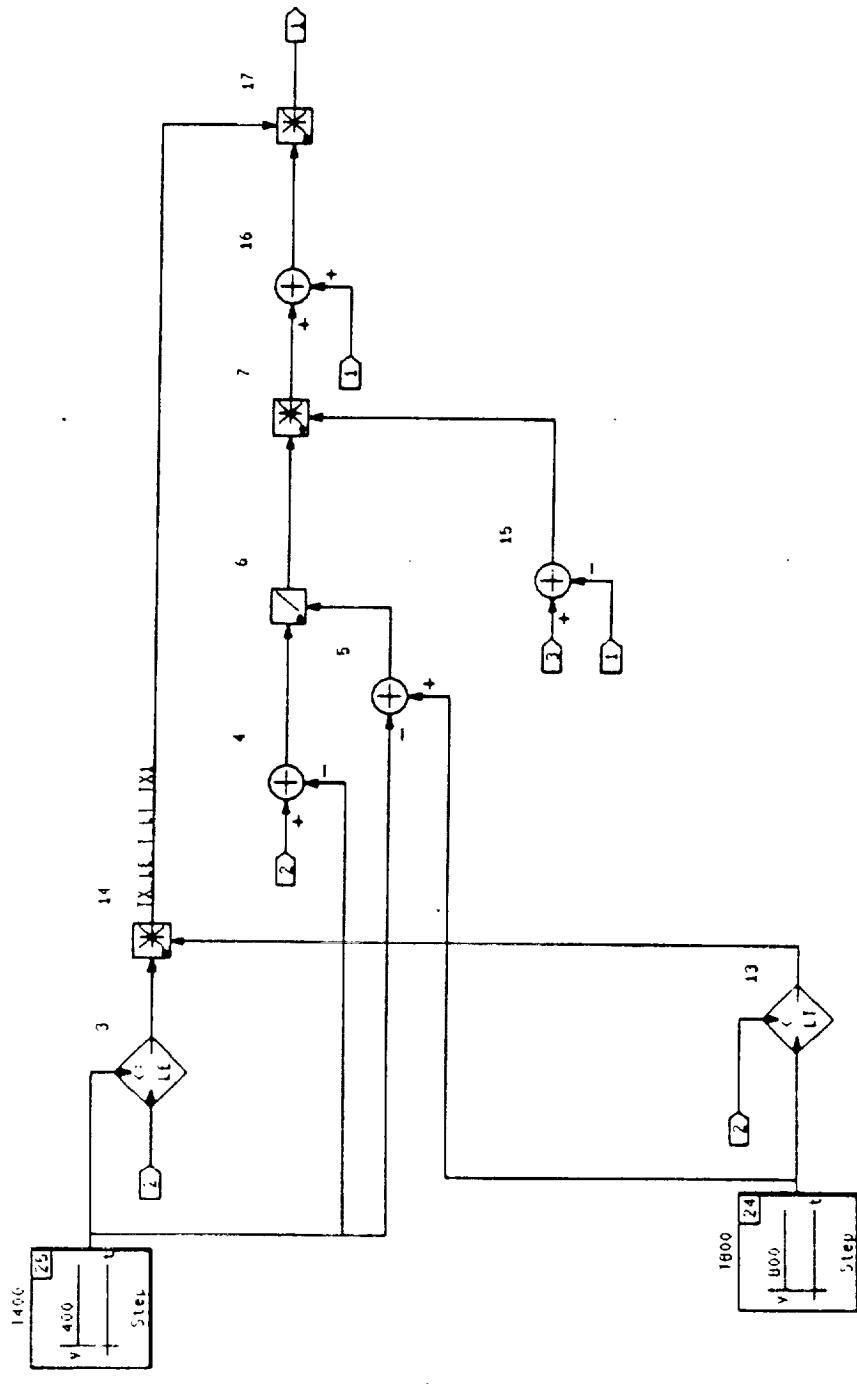
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
T_c 3 1



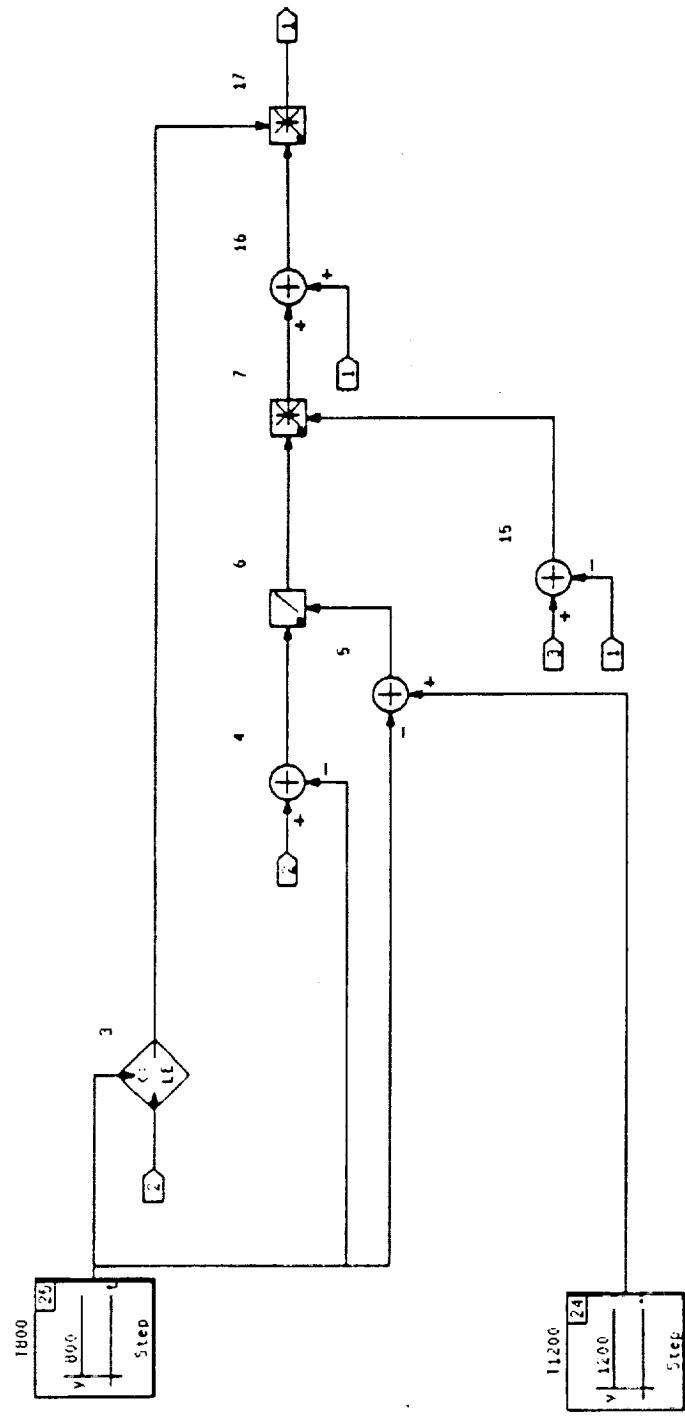
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
T7 3 1



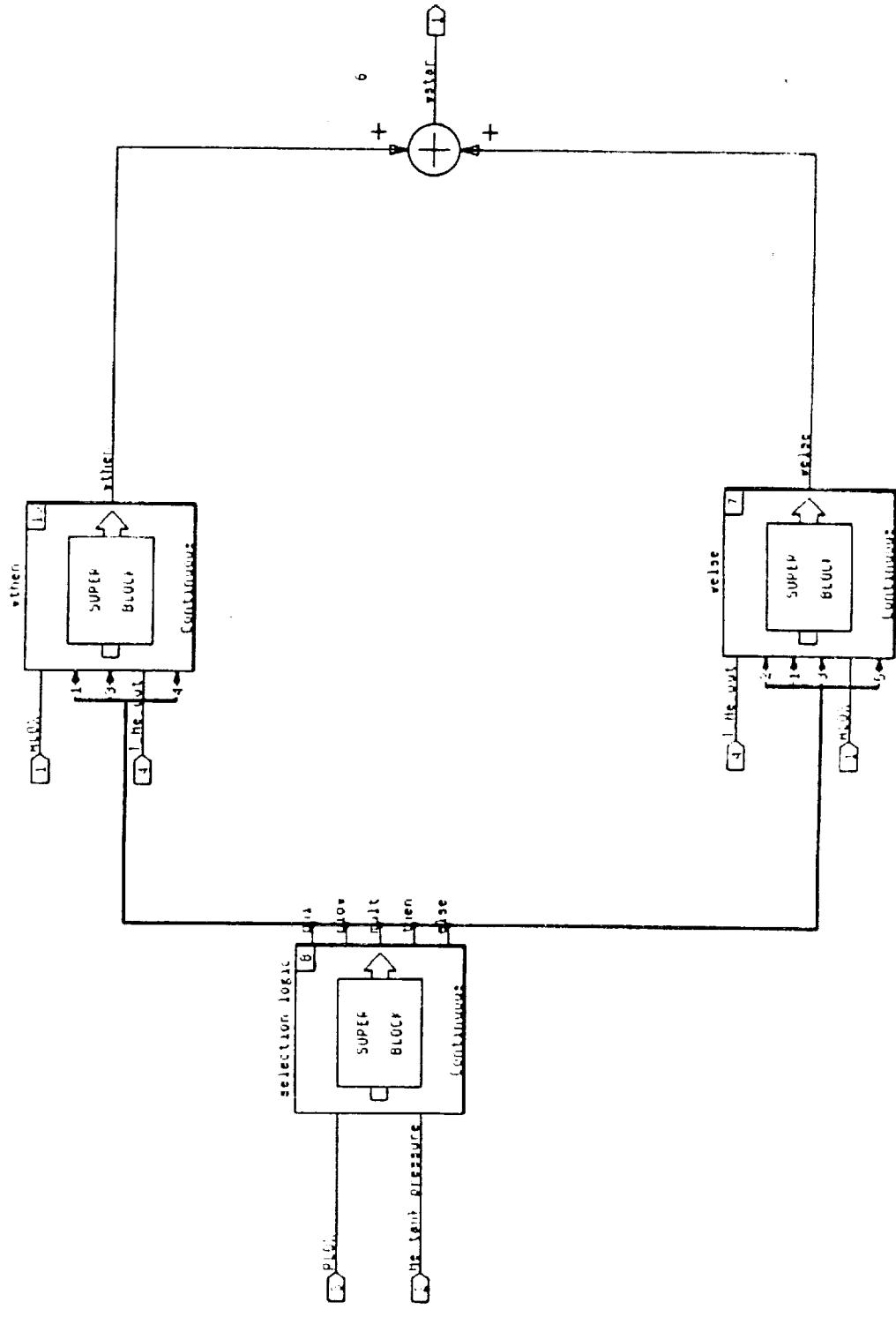
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
18 3 1



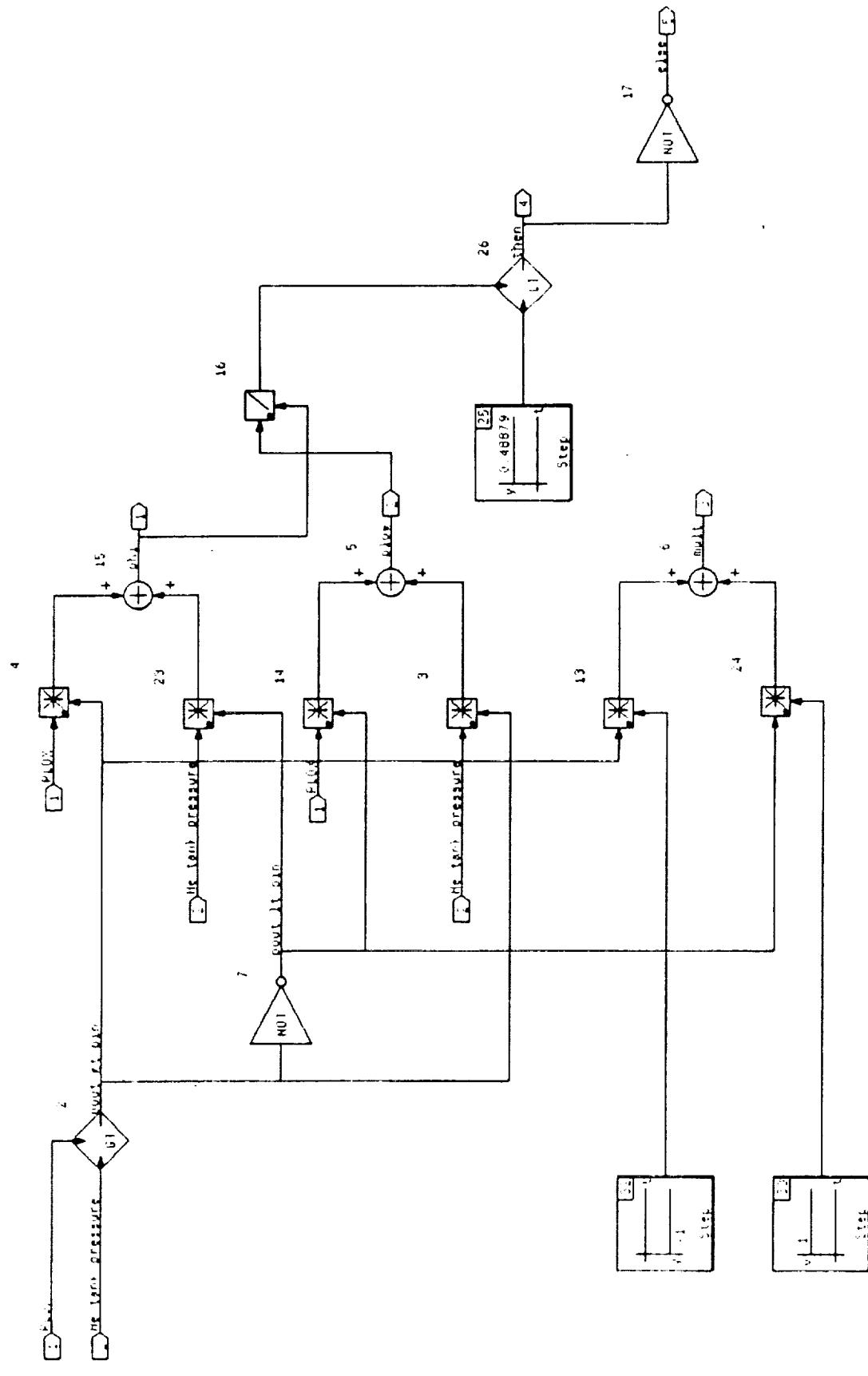
HINTS

Continuous Super-Block
Ext. Inputs
Compressible Flow 4 Ext. Outputs
1



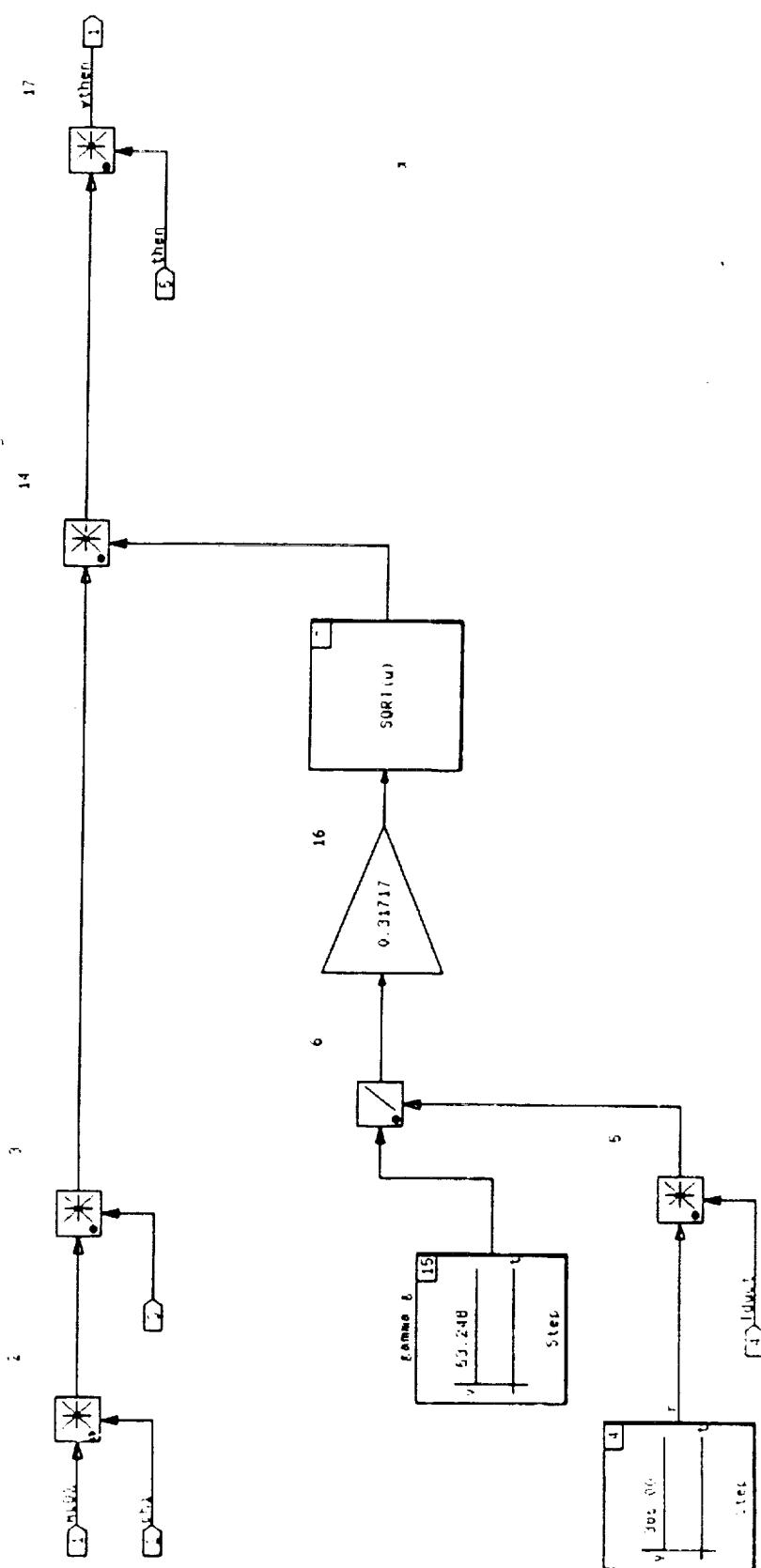
HINTS

Continuous Super-block Ext. Inputs Ext. Outputs
Selection logic 2 5



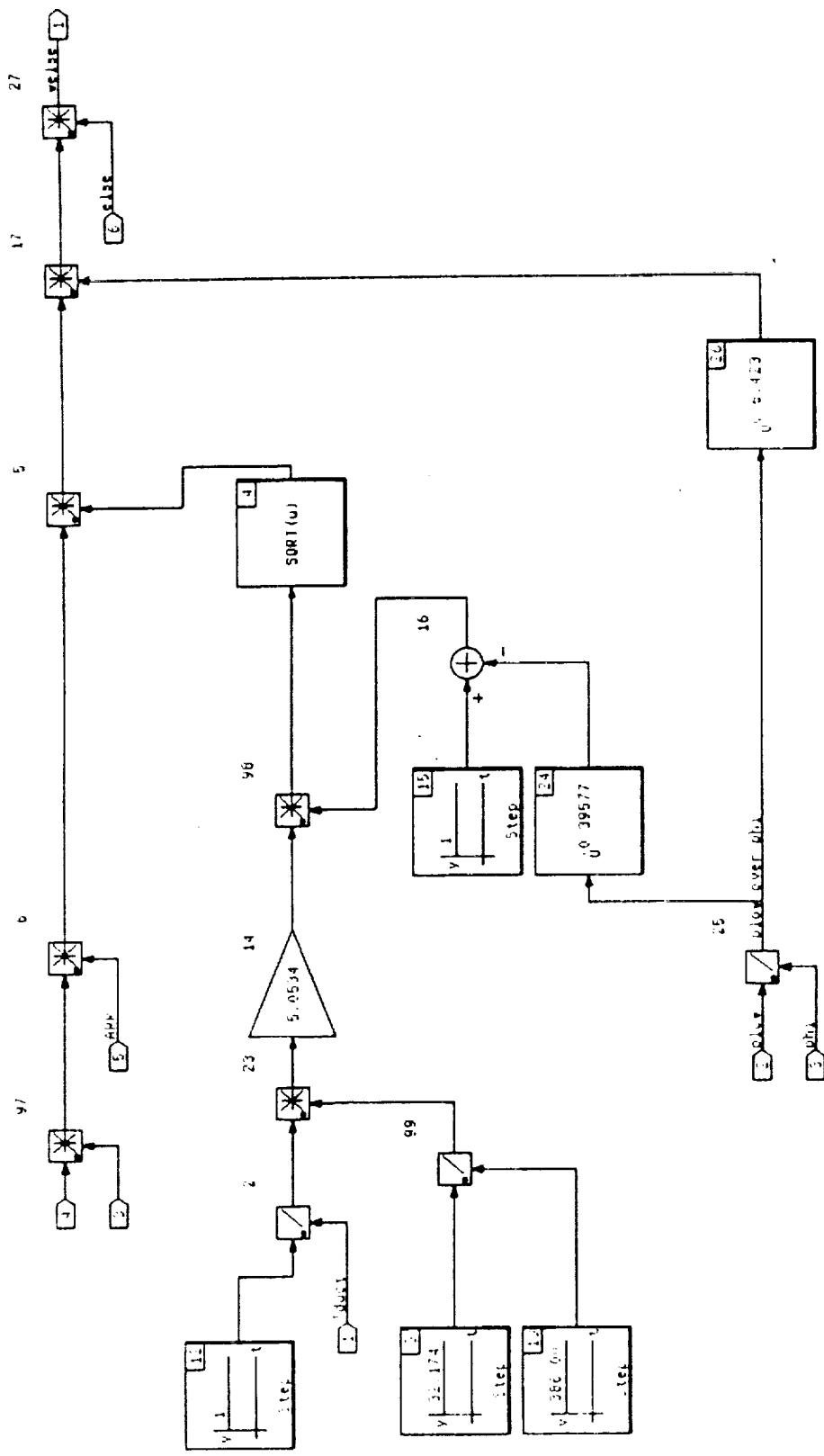
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
wtheri 5 1



HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
welle



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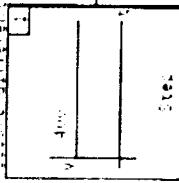
HINTS

Continuous Super-Block
Sys4Z L02_LH2 Small

Ext. Inputs Ext. Outputs

1 5

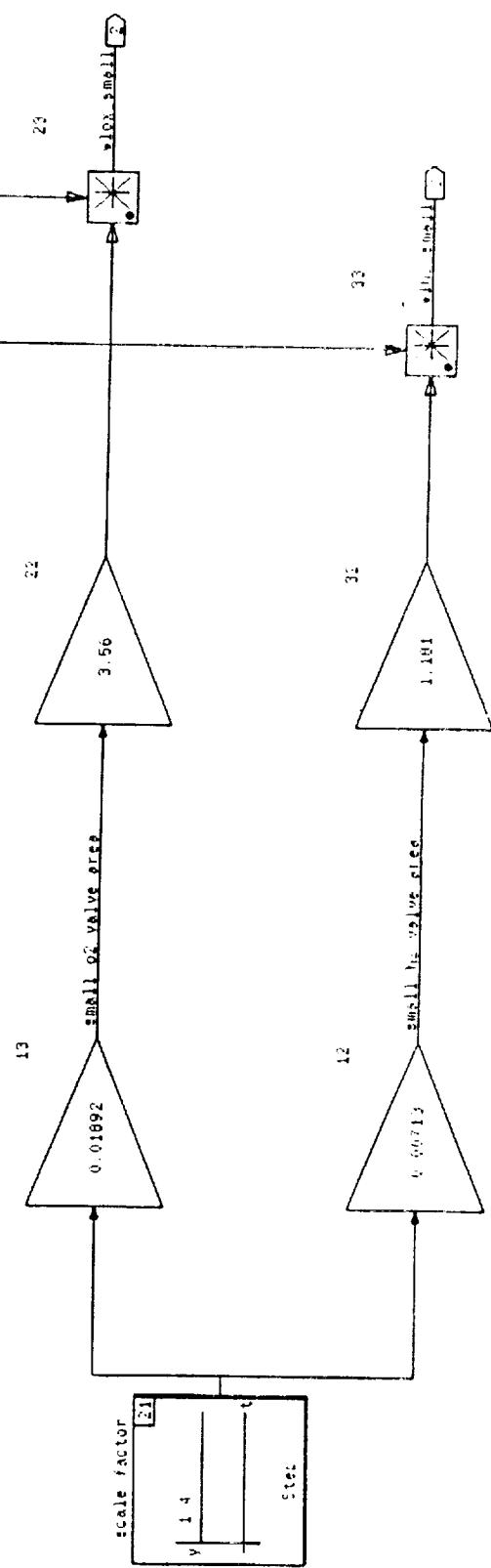
Small tank
pressure difference



$$14 \quad \text{small tank pressure} +$$

$$15 \quad \text{small tank pressure} -$$

SORT(1)

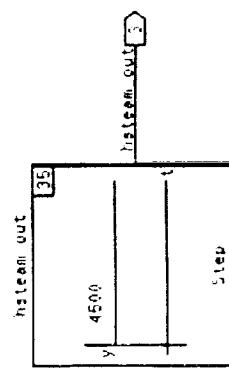
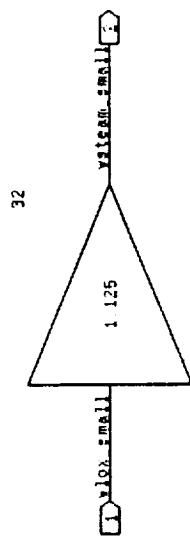
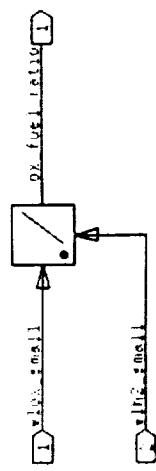


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HINTS

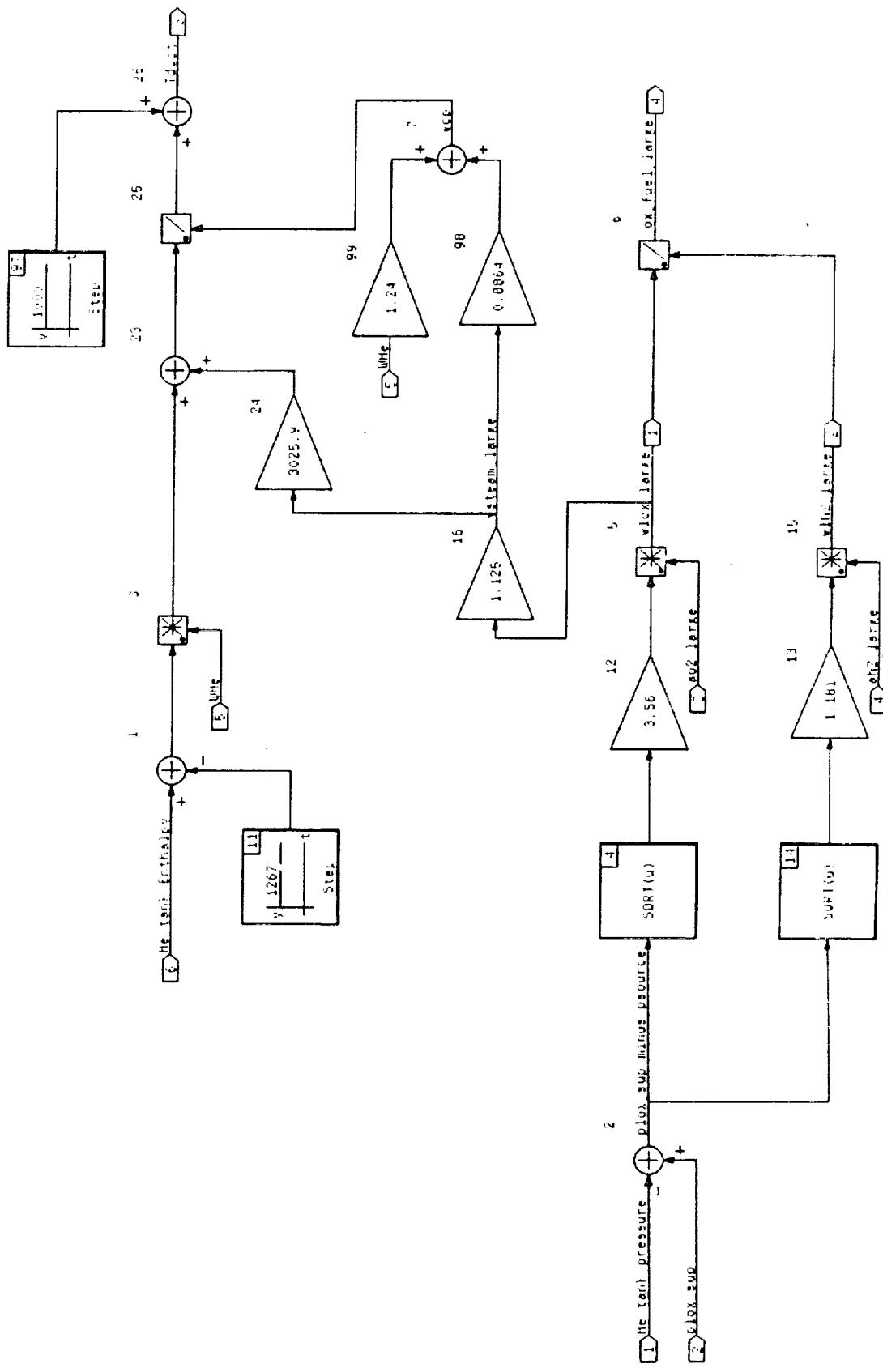
Continuous Super-Block
Sys42 small heater

Ext. Inputs 2 3
Ext. Outputs 5



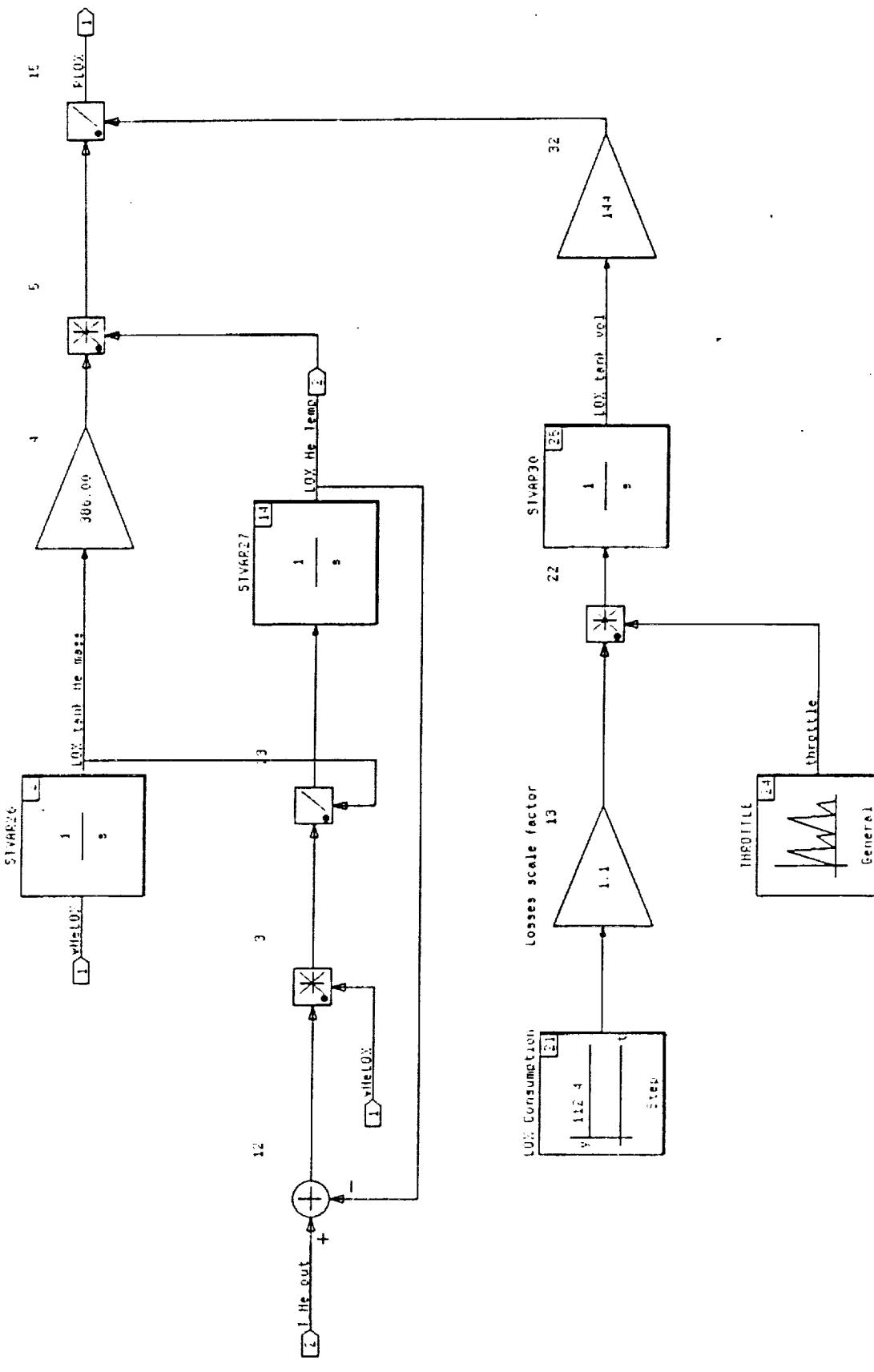
HINTS

Continuous Super-Block: Sys4E_Large_heater
Ext. Inputs: 6, 4
Ext. Outputs: 5, 2



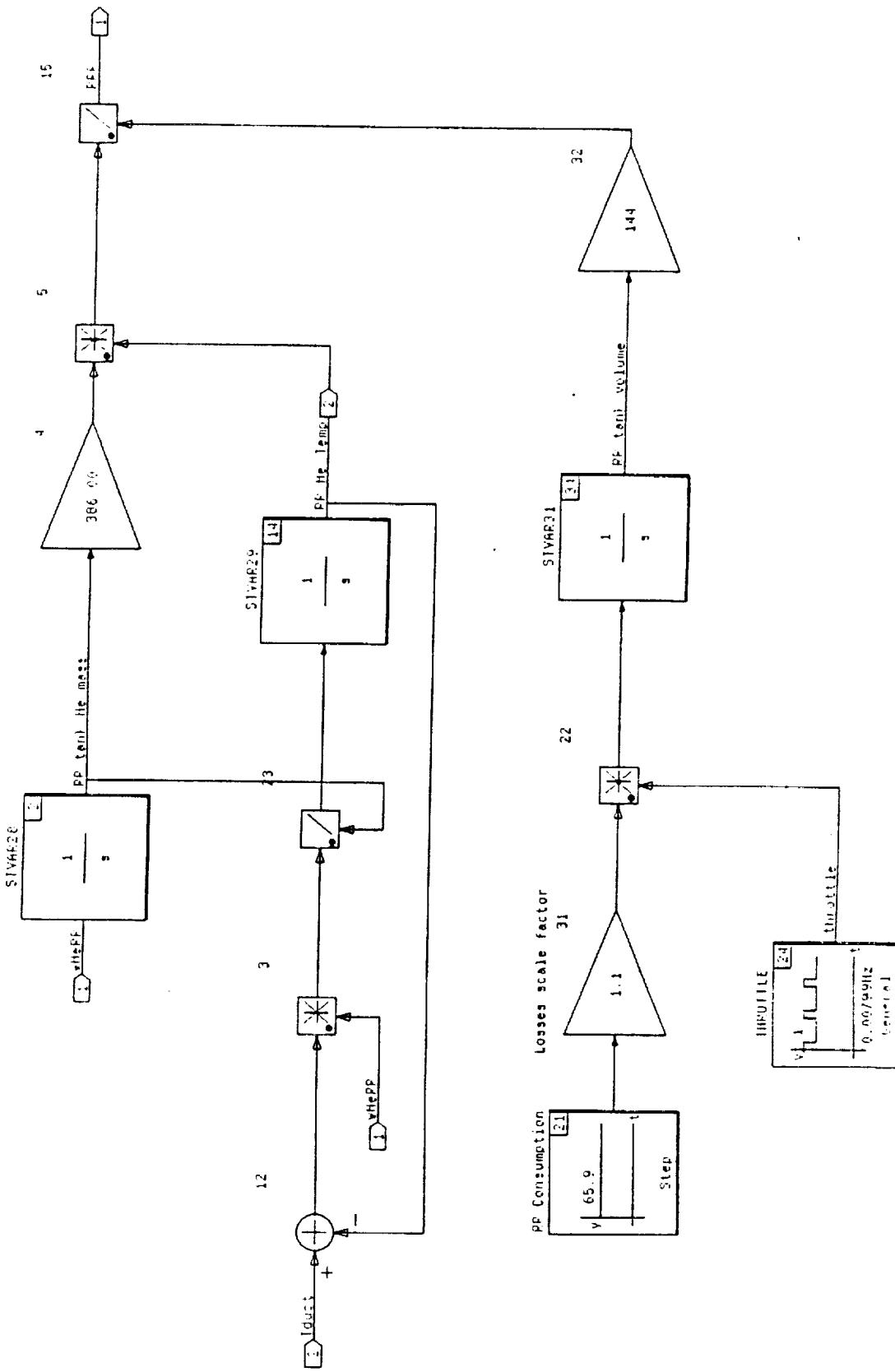
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
 LOX Tank 2



HINTS

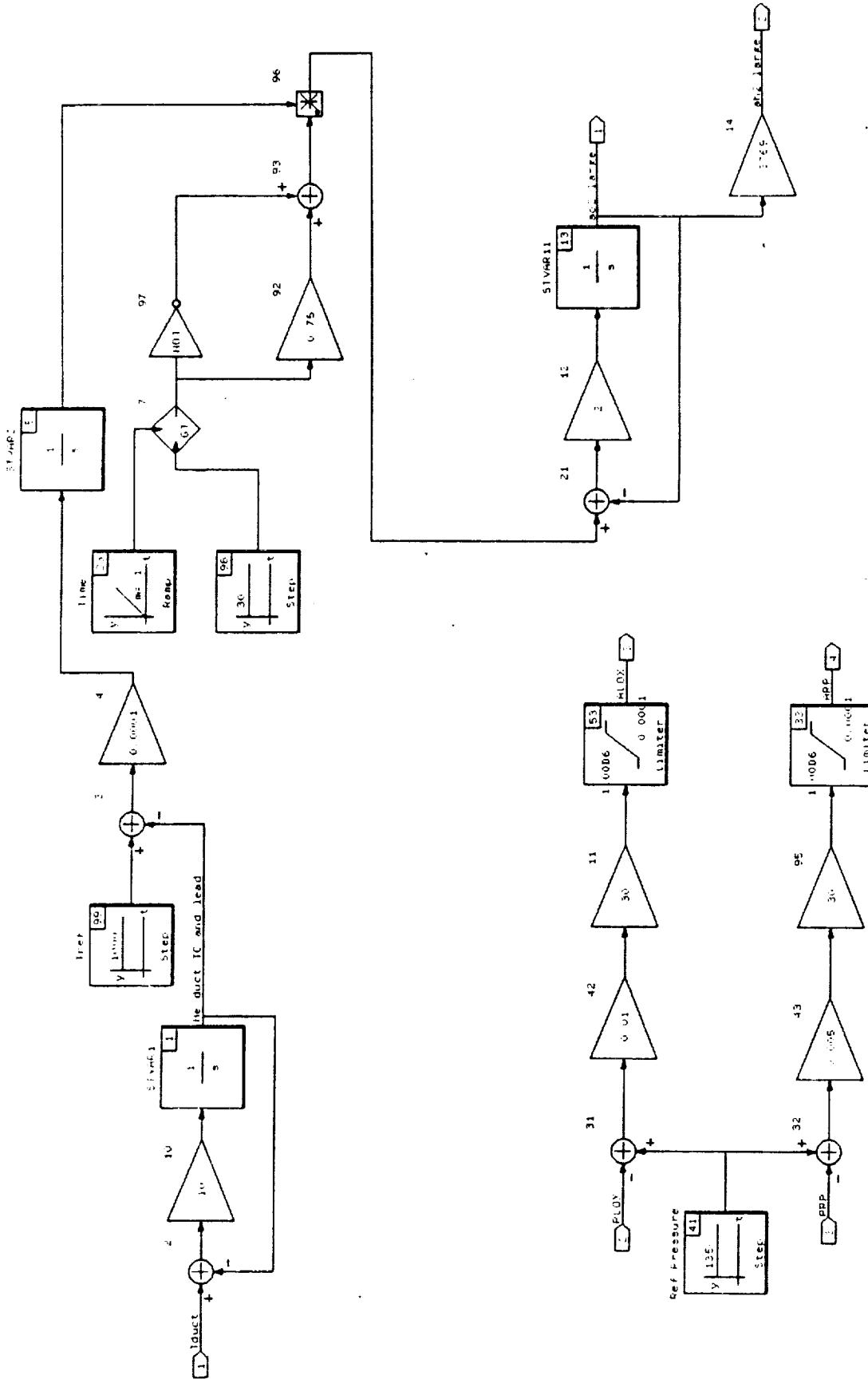
Continuous Super-Block Ext. Inputs Ext. Outputs
RF Thrust



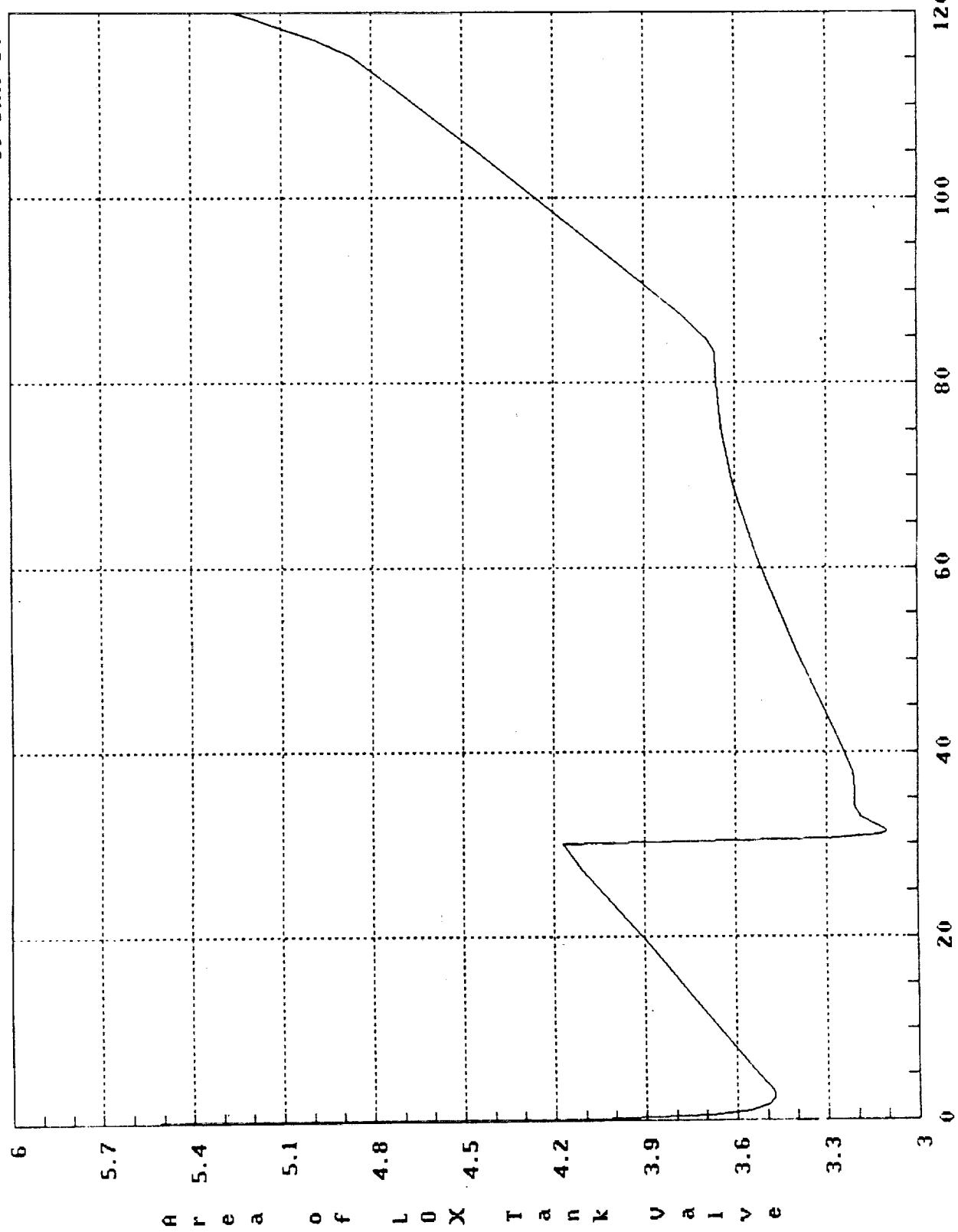
HINTS

Continuous Super-Bloc
Sys4E Controller

Ext. Inputs Ext. Outputs
3 4



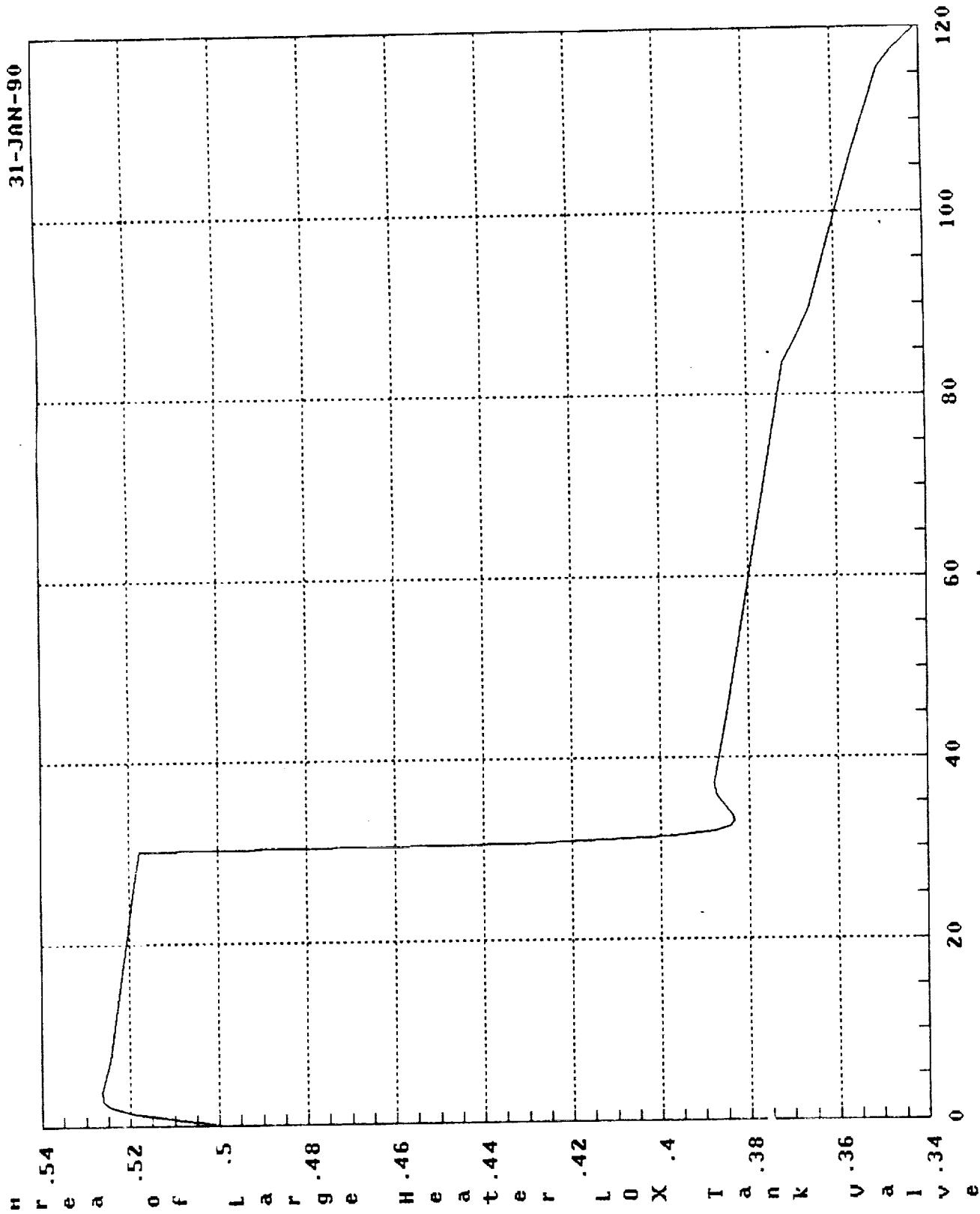
31-JAN-90



CONFIGURATION 42

10^3

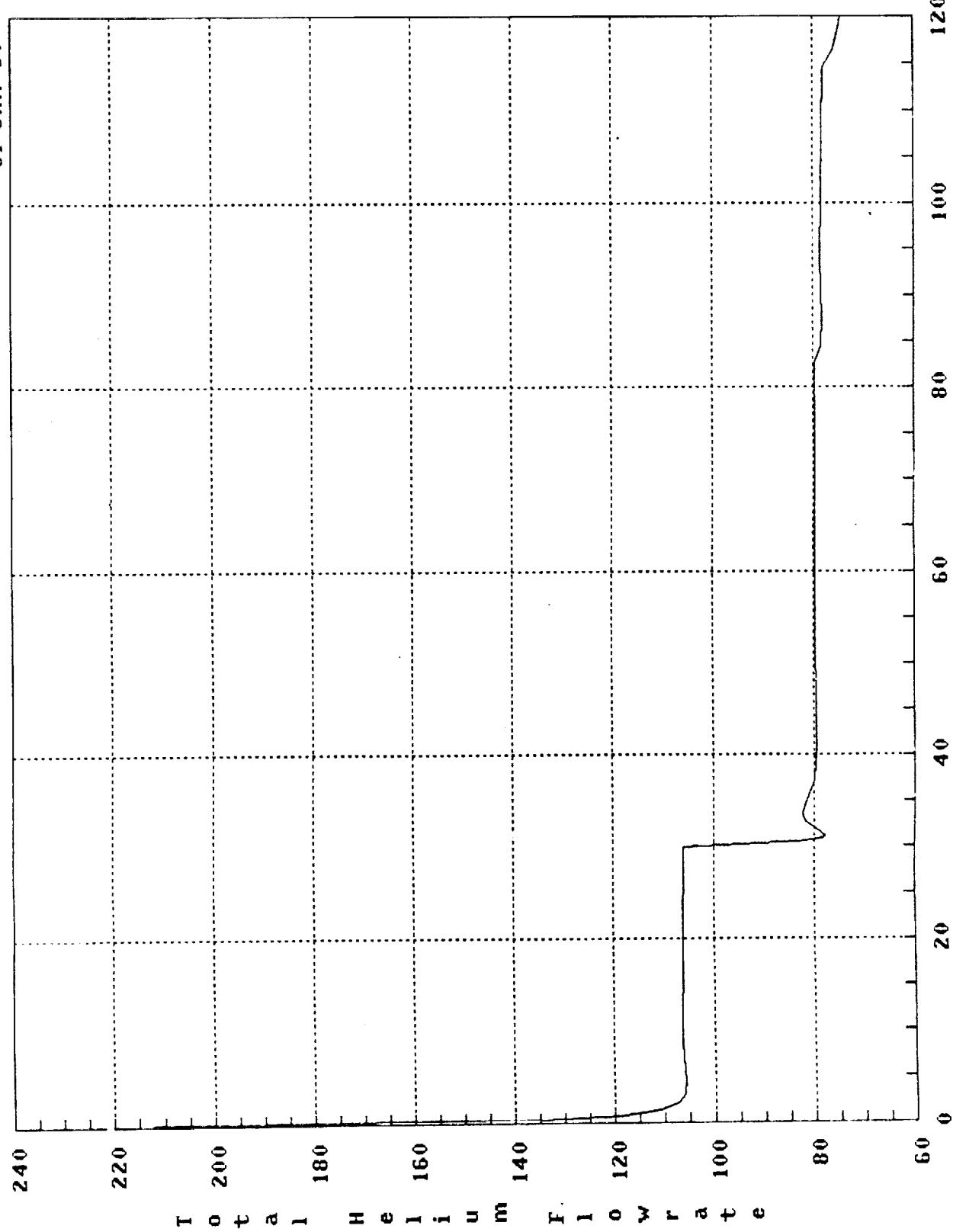
31-JAN-90



CONFIGURATION 42

104

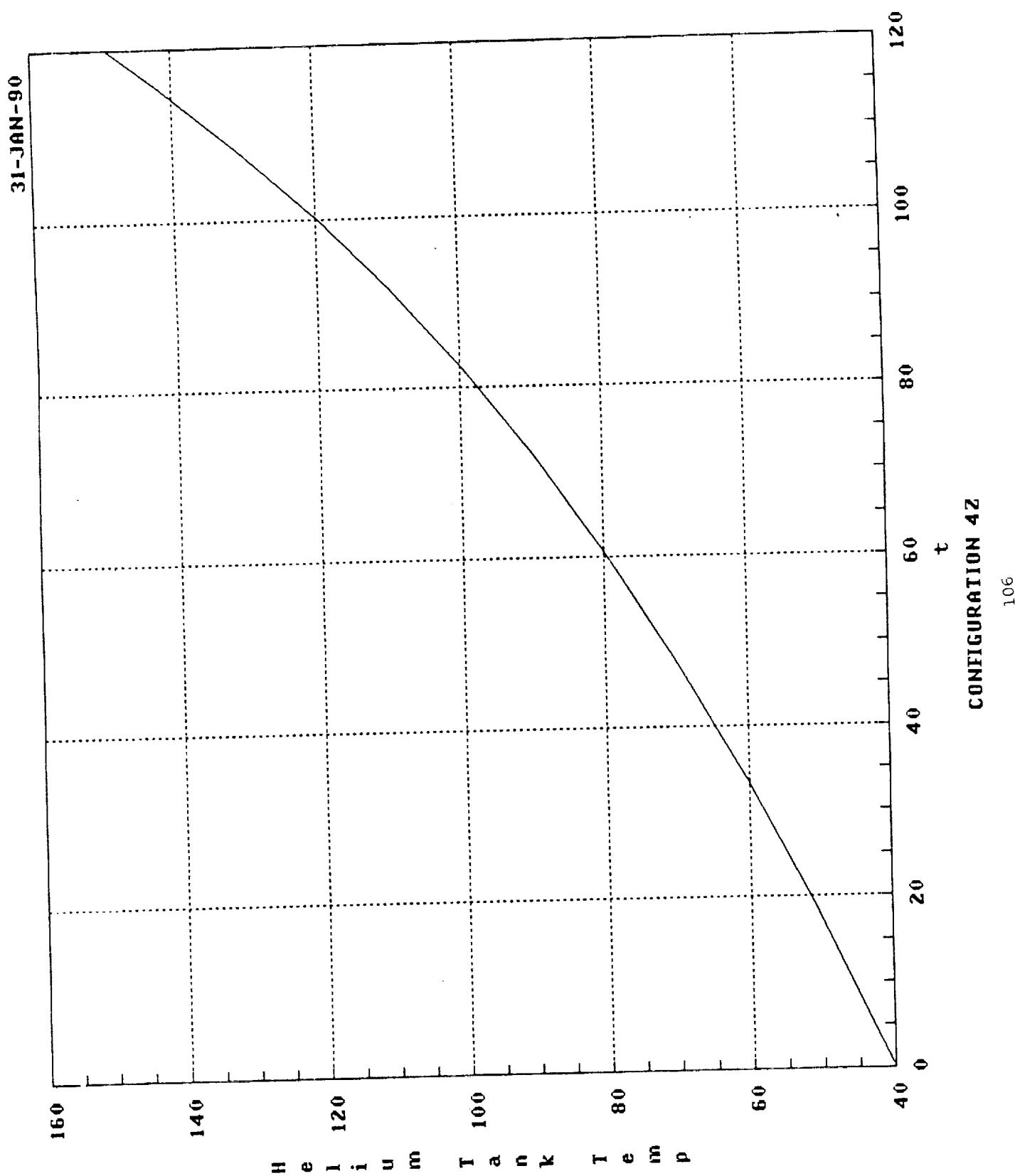
31-JAN-90



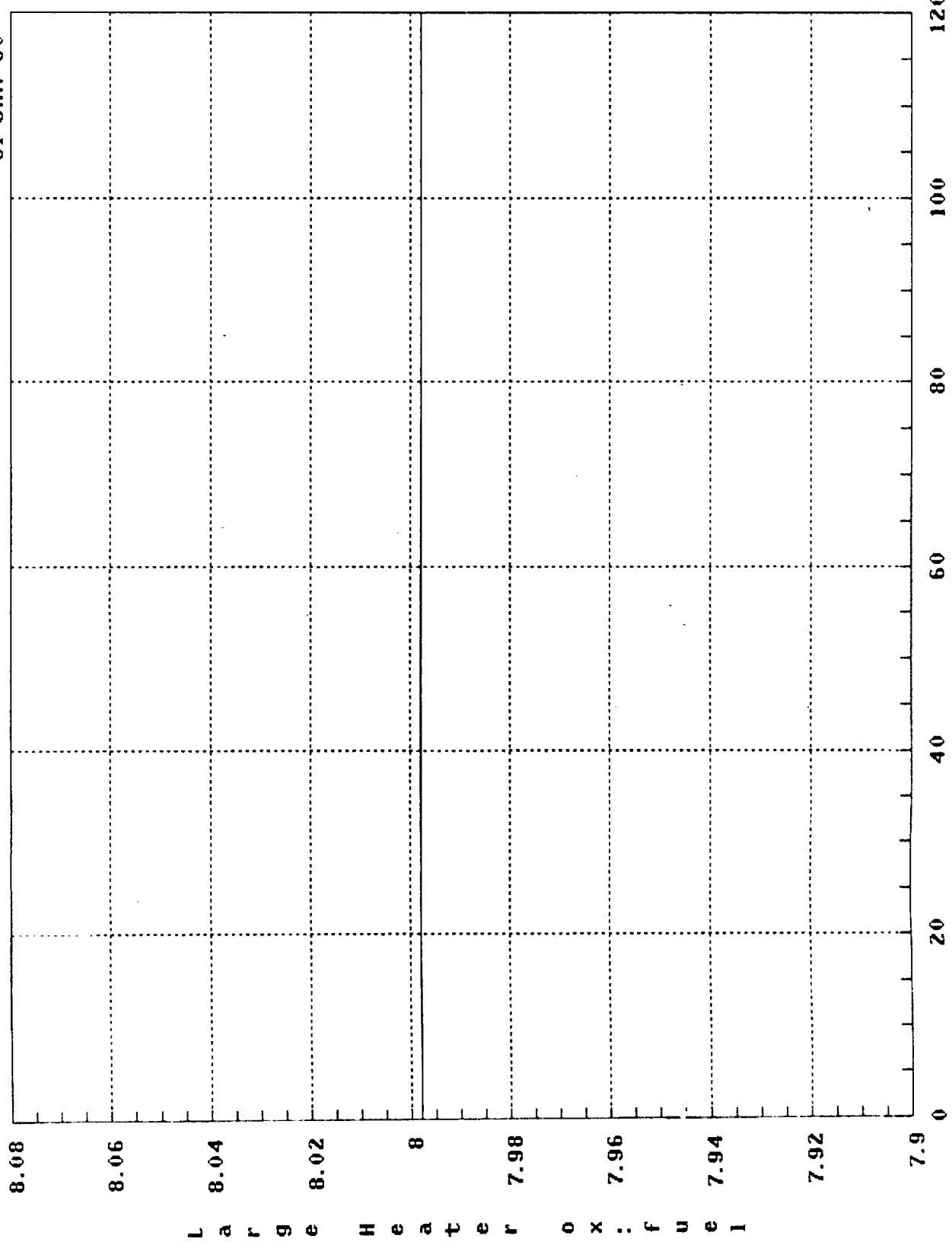
CONFIGURATION 42

10^5

31-JAN-90



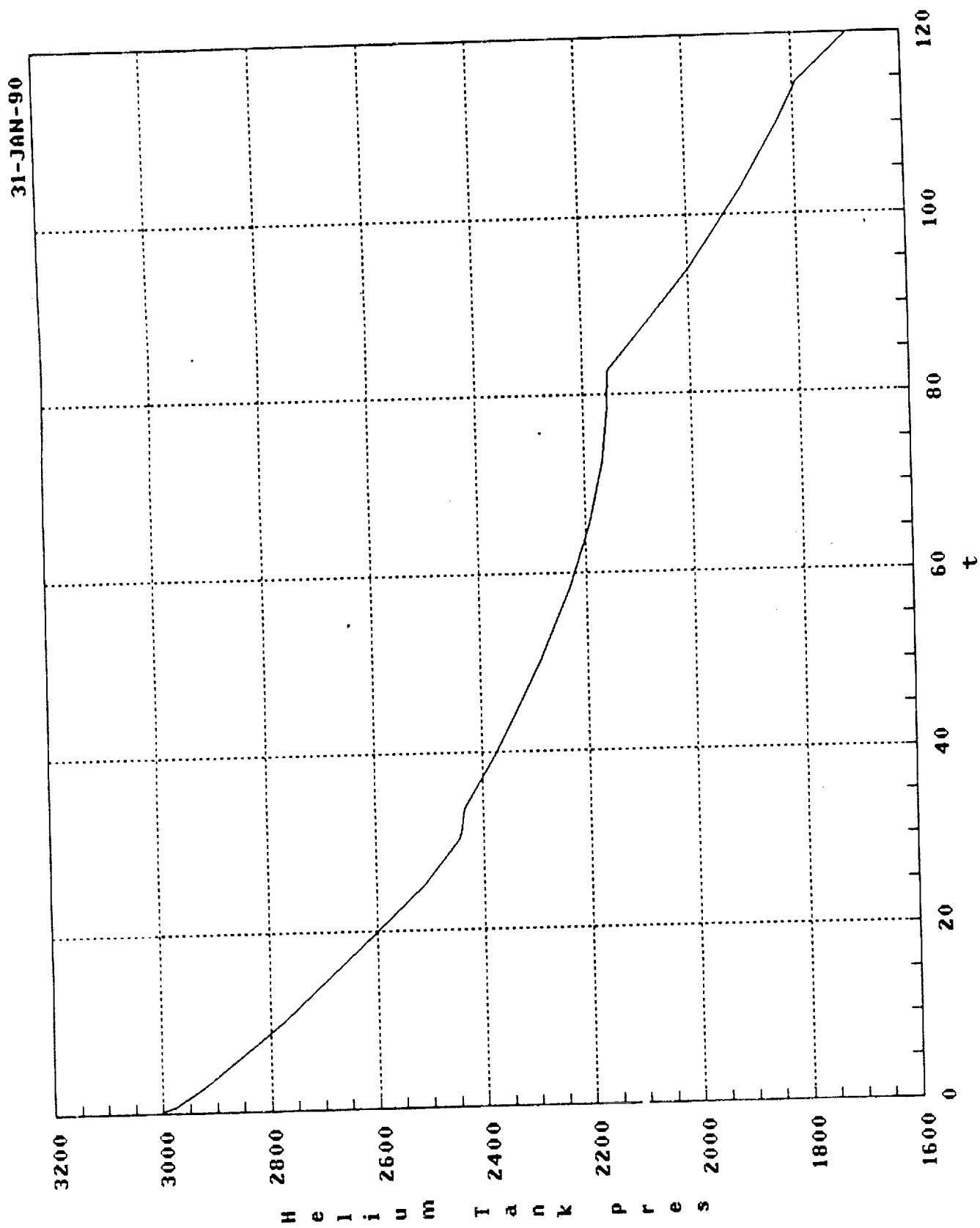
31-JAN-90



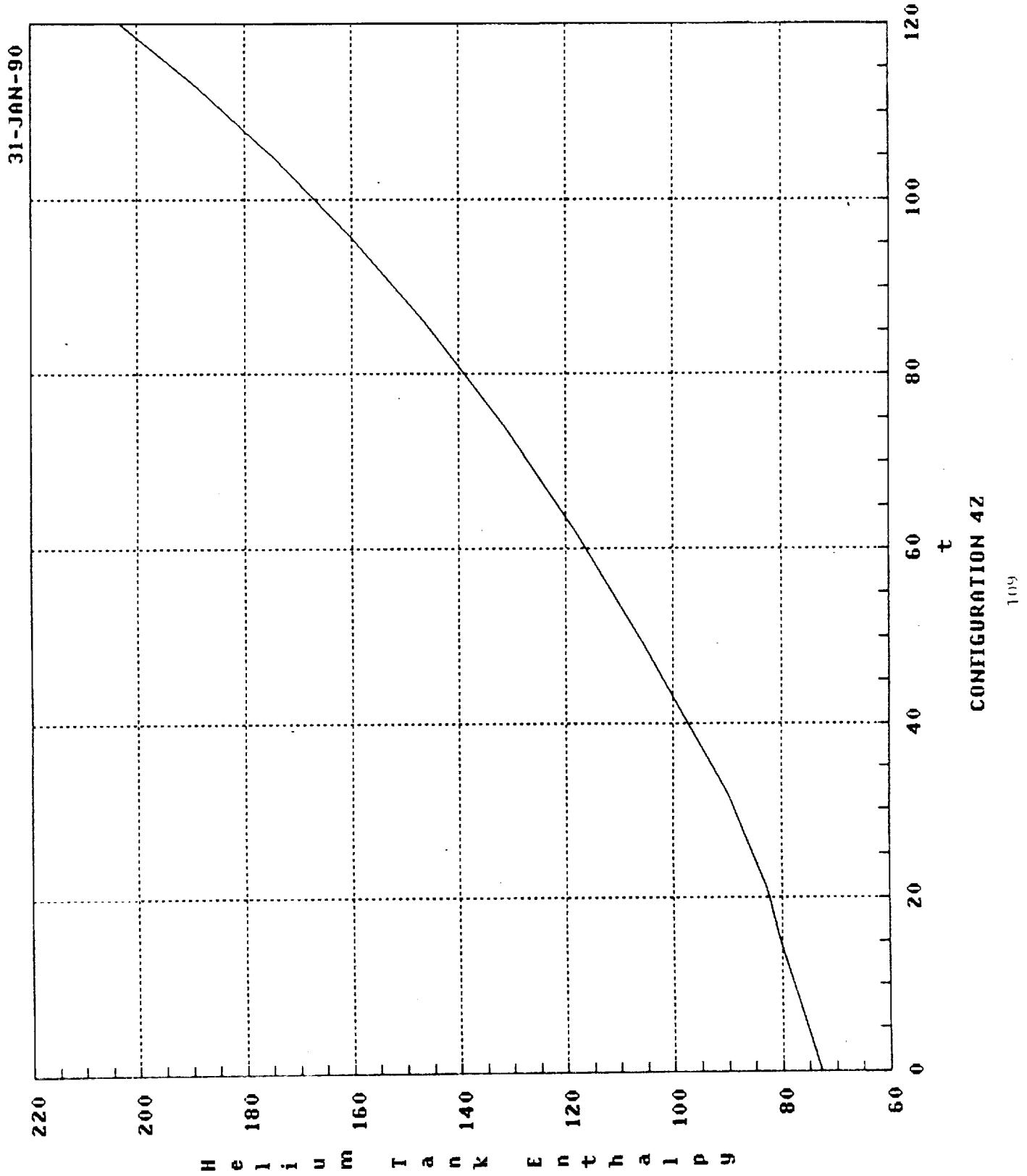
CONFIGURATION 42

10^7

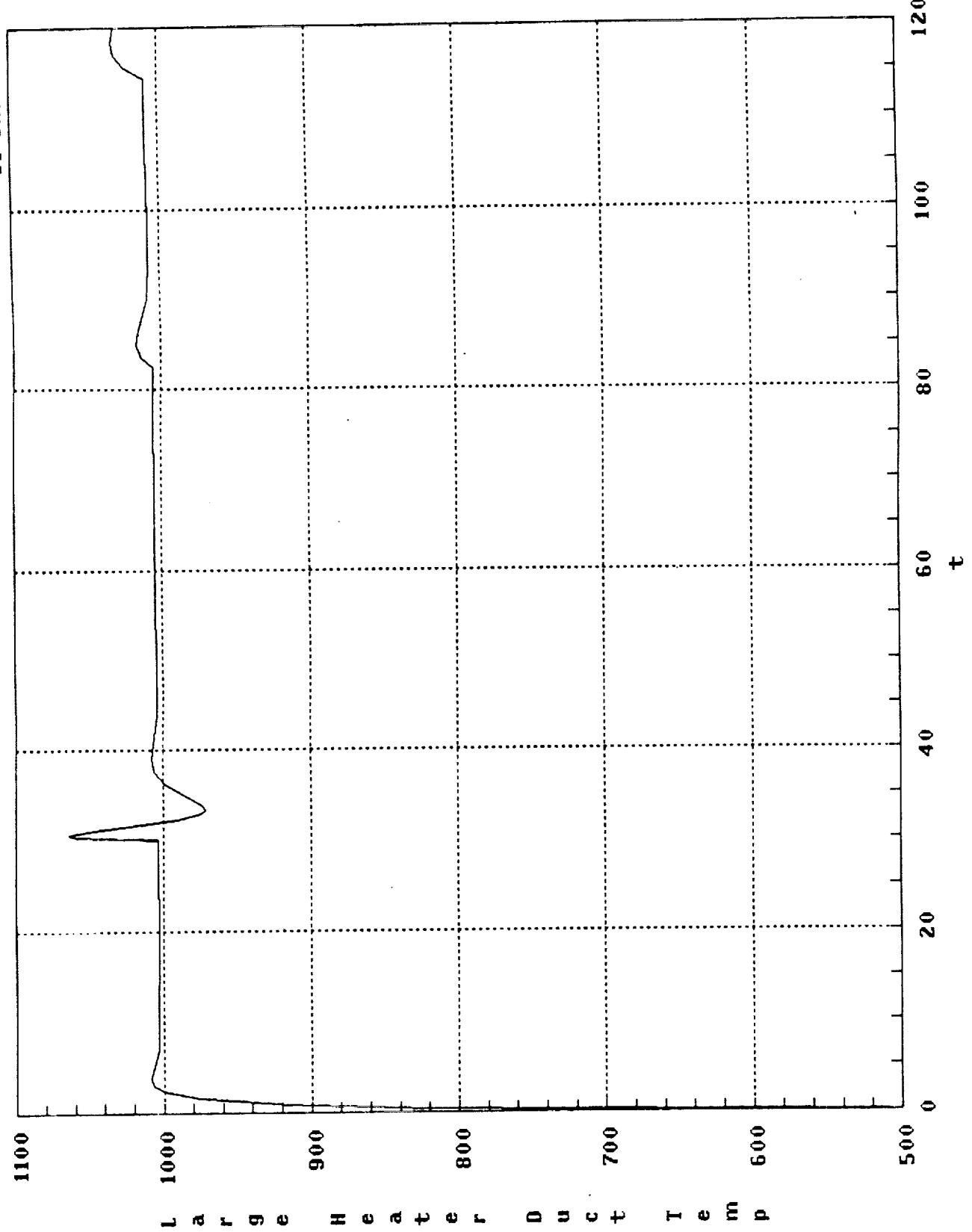
31-JAN-90



CONFIGURATION 42
108



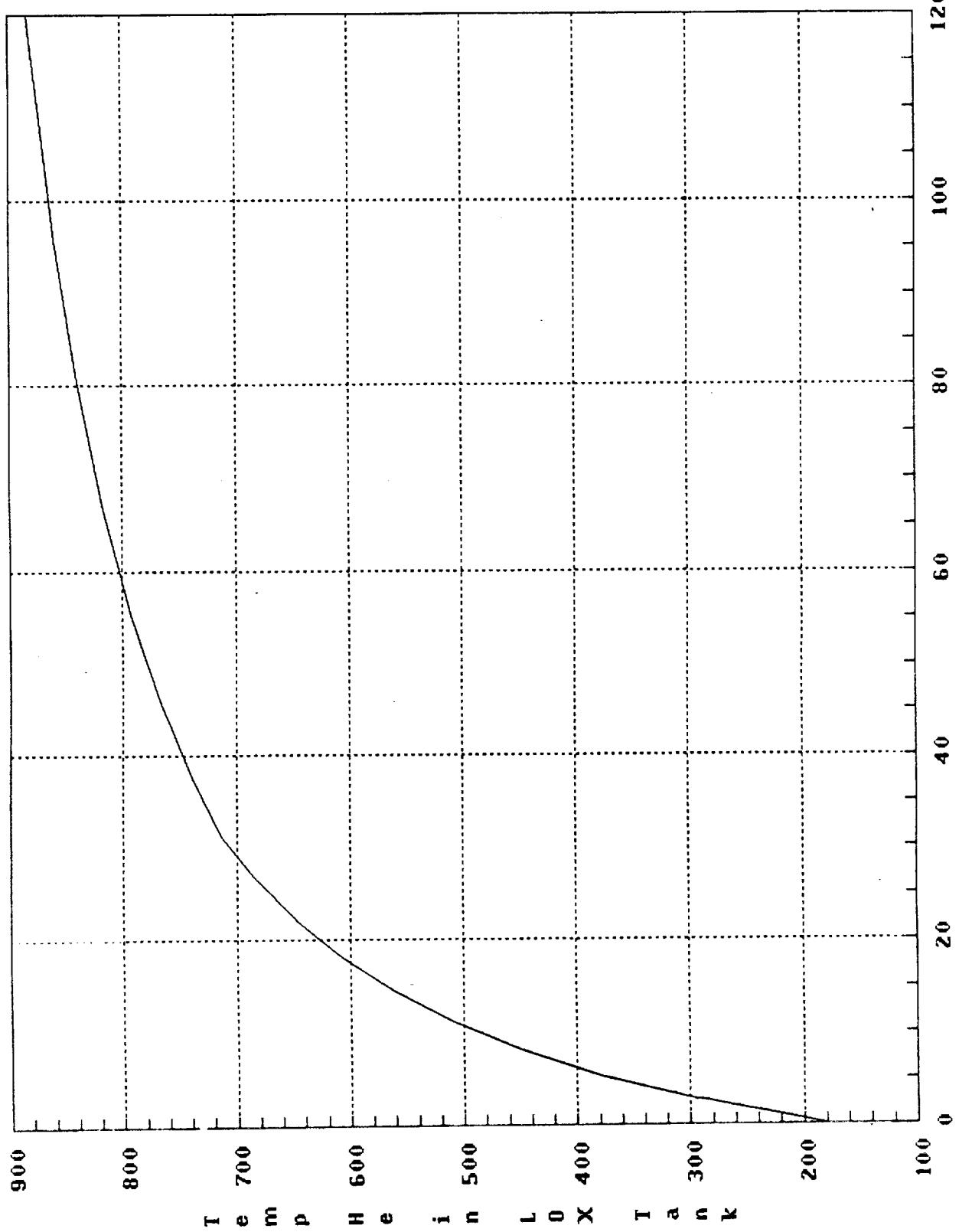
31-JAN-90



CONFIGURATION 42

110

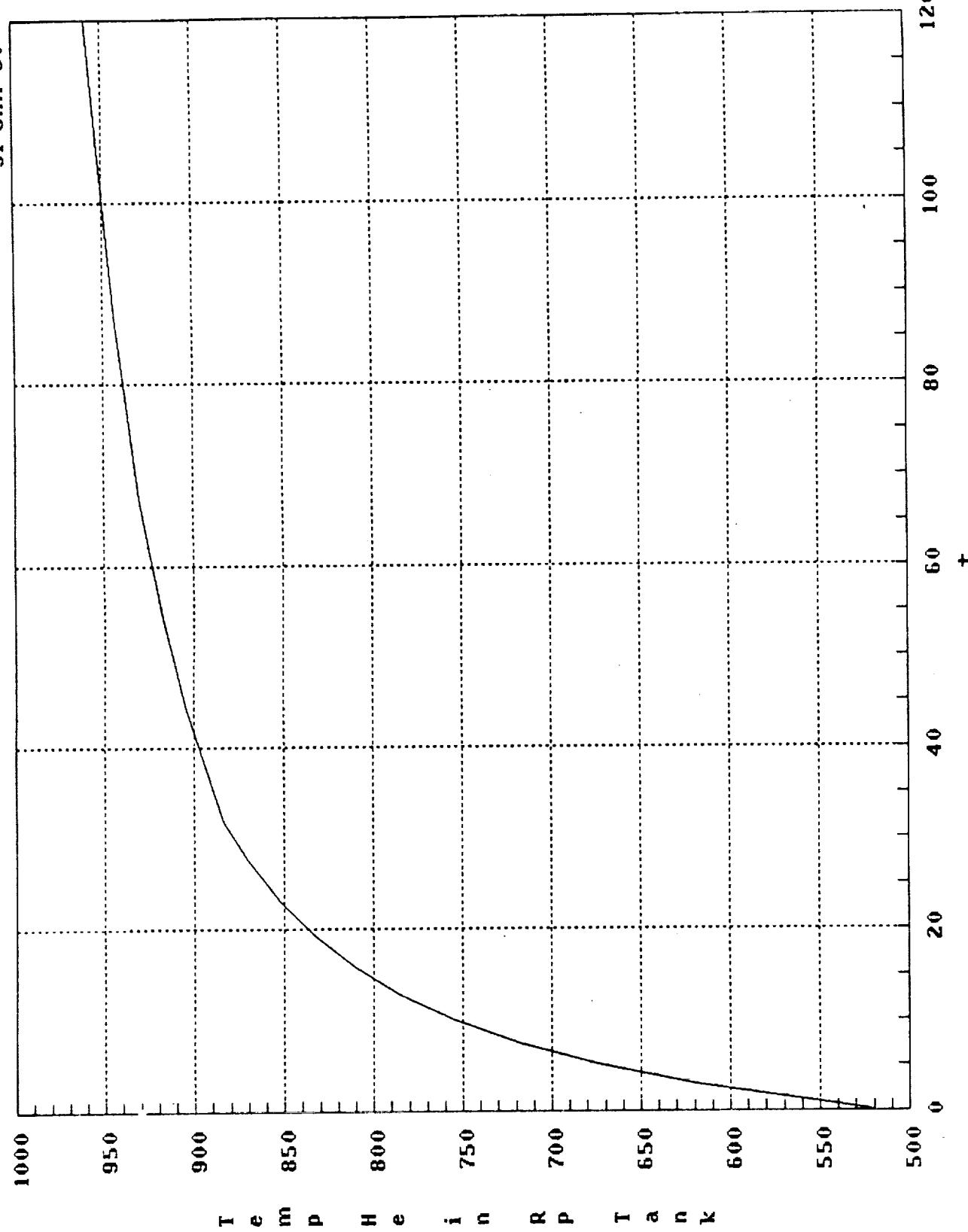
31-JAN-90



CONFIGURATION 42

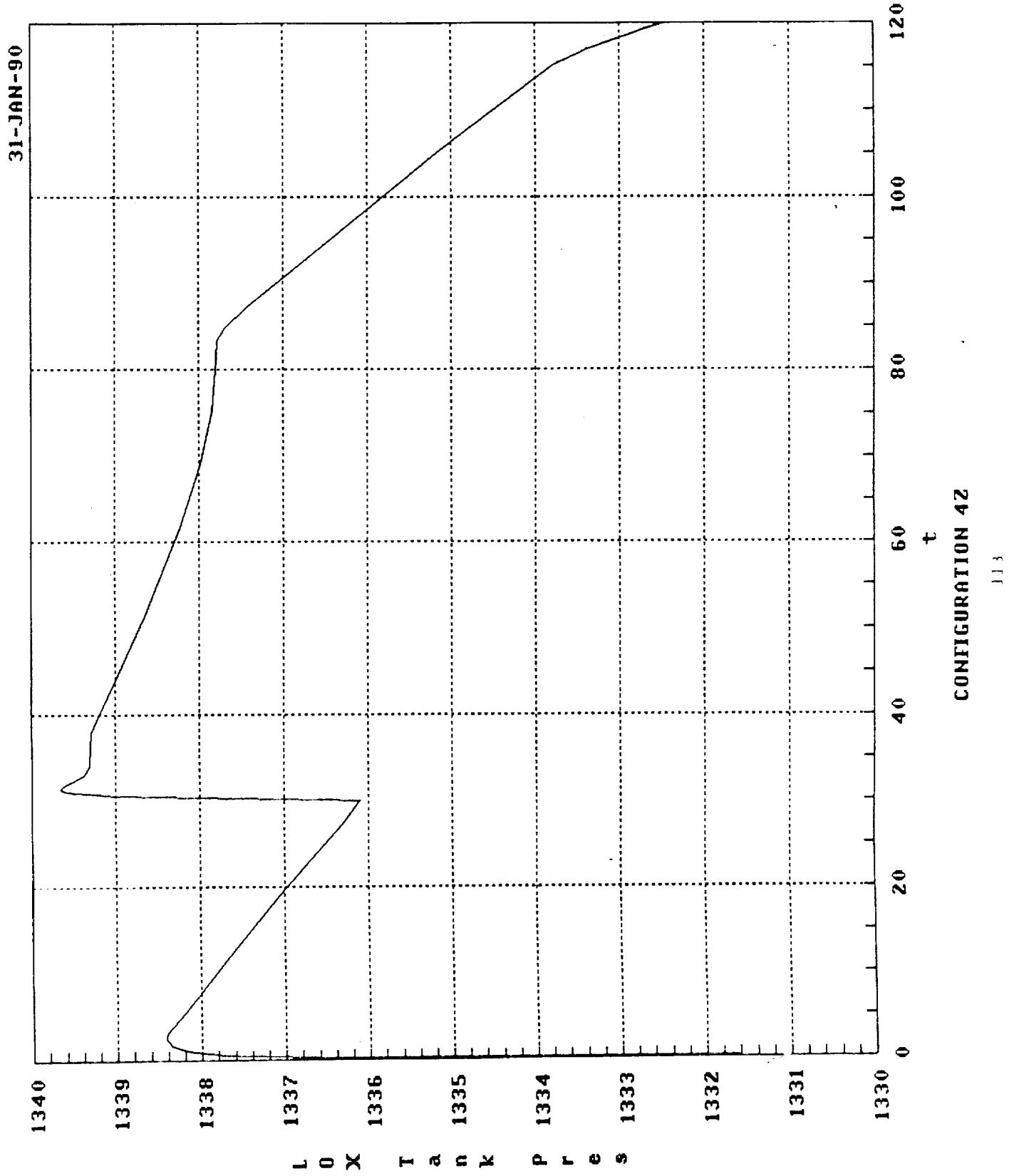
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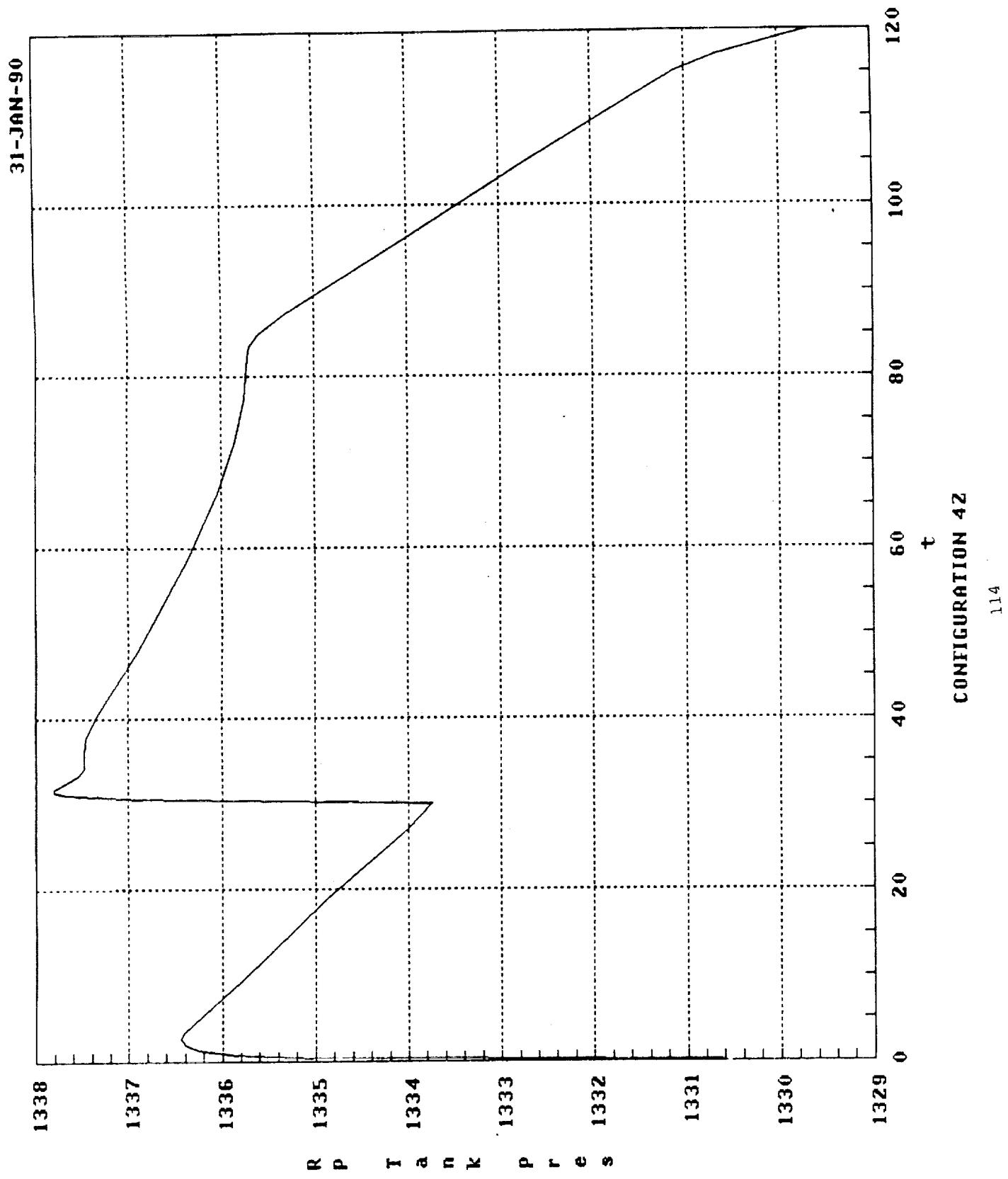
31-JAN-90



CONFIGURATION 42

112



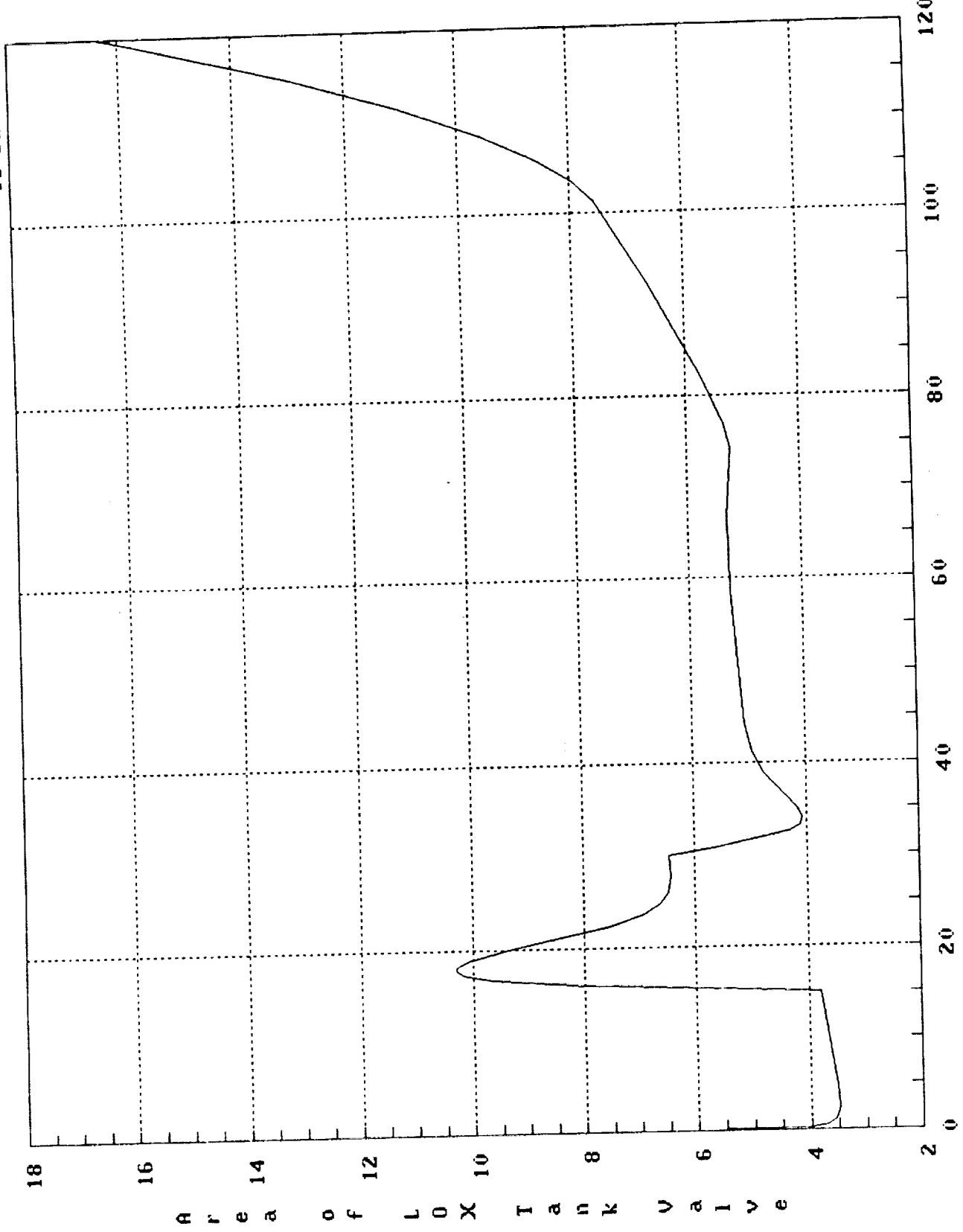


CONFIGURATION 4Z - - FAILURE MODES

- TOTAL HELIUM FLOW DIVIDED 50% PER PRIMARY HEATER PRIOR TO FAILURE
- LOSS OF 1 PRIMARY HEATER AT $T = 15 \text{ SEC}$
- TOTAL HELIUM FLOW RATE THROUGH "GOOD" HEATER AFTER FAILURE
- HEATER LOX/LH₂ VALVES SET AT 25% AT START-UP
- HEATER LOX/LH₂ VALVES NOT ADJUSTED FOR "FAILURE" MODE
- PERCENTAGE OF TOTAL HELIUM FLOW RATE THROUGH GOOD HEATER

$T = 0 \rightarrow 15 \text{ SEC}$	50%
$T = 15 \rightarrow 30 \text{ SEC}$	100%
$T = 30 \rightarrow 120 \text{ SEC}$	75%

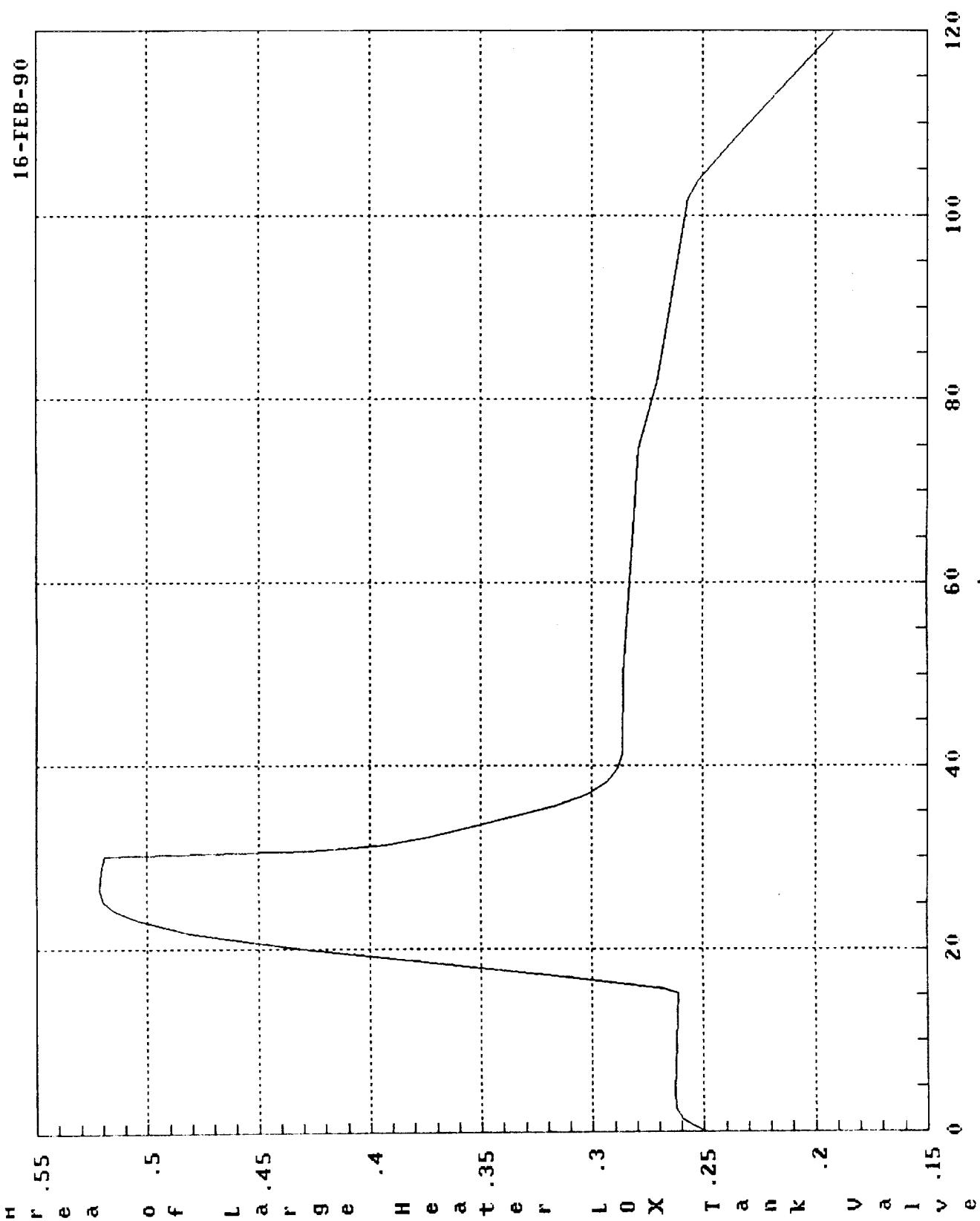
16-FEB-90



CONFIGURATION 42 FAILED HEATER AT 15 SECONDS

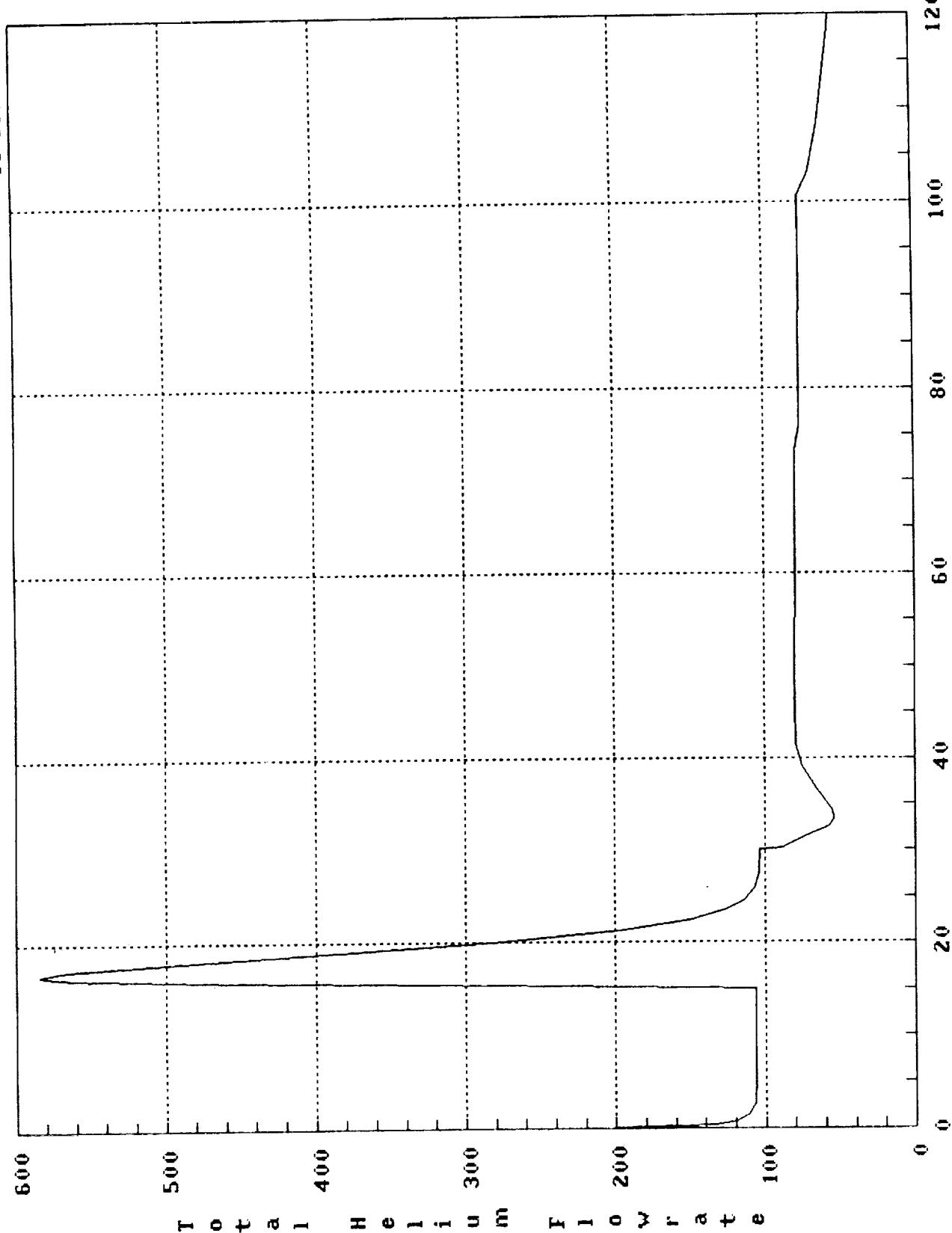
116

16-FEB-90



CONFIGURATION 42 FAILED HEATER AT 15 SECONDS

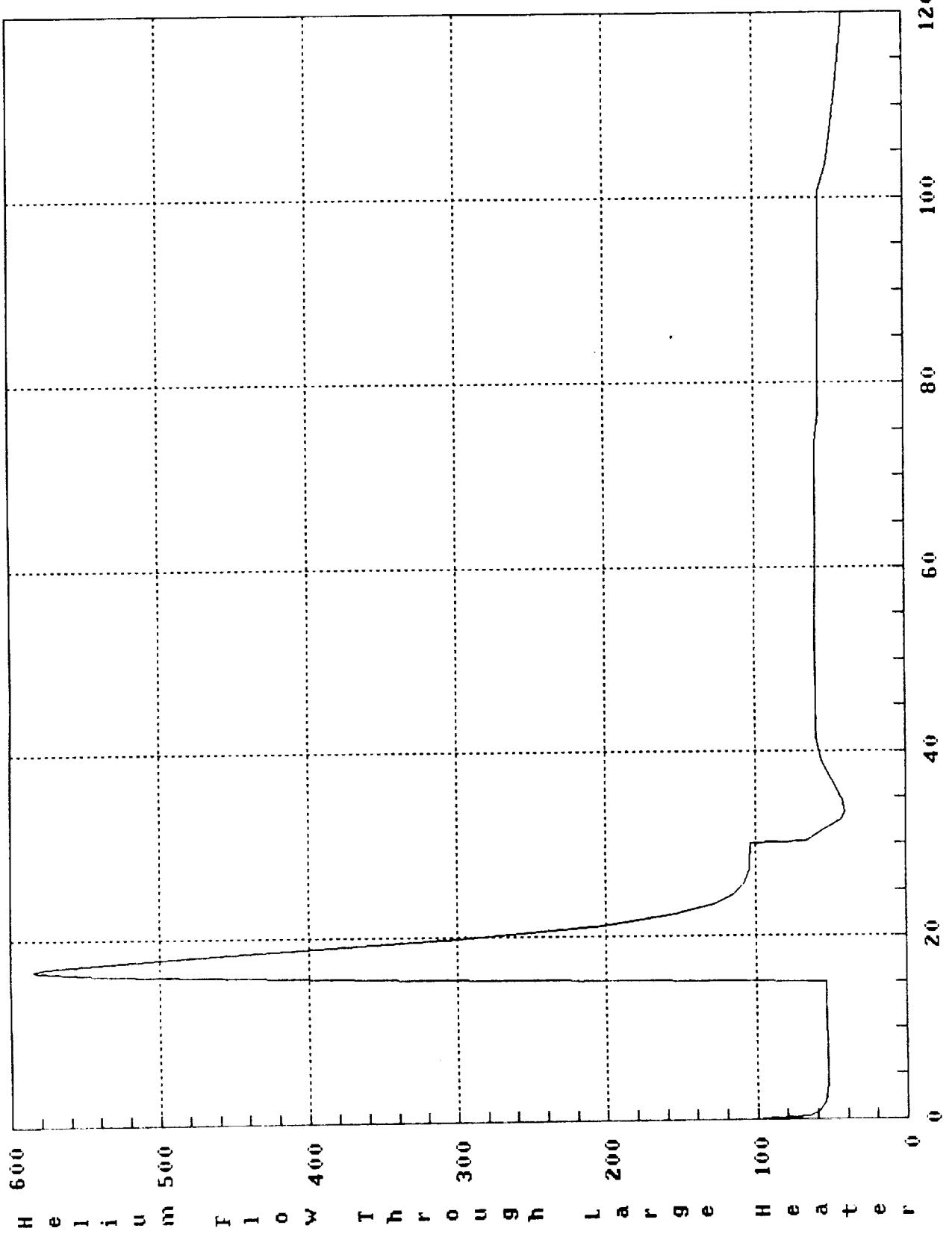
16-FEB-90



CONFIGURATION 42 FAILED HEATER AT 15 SECONDS

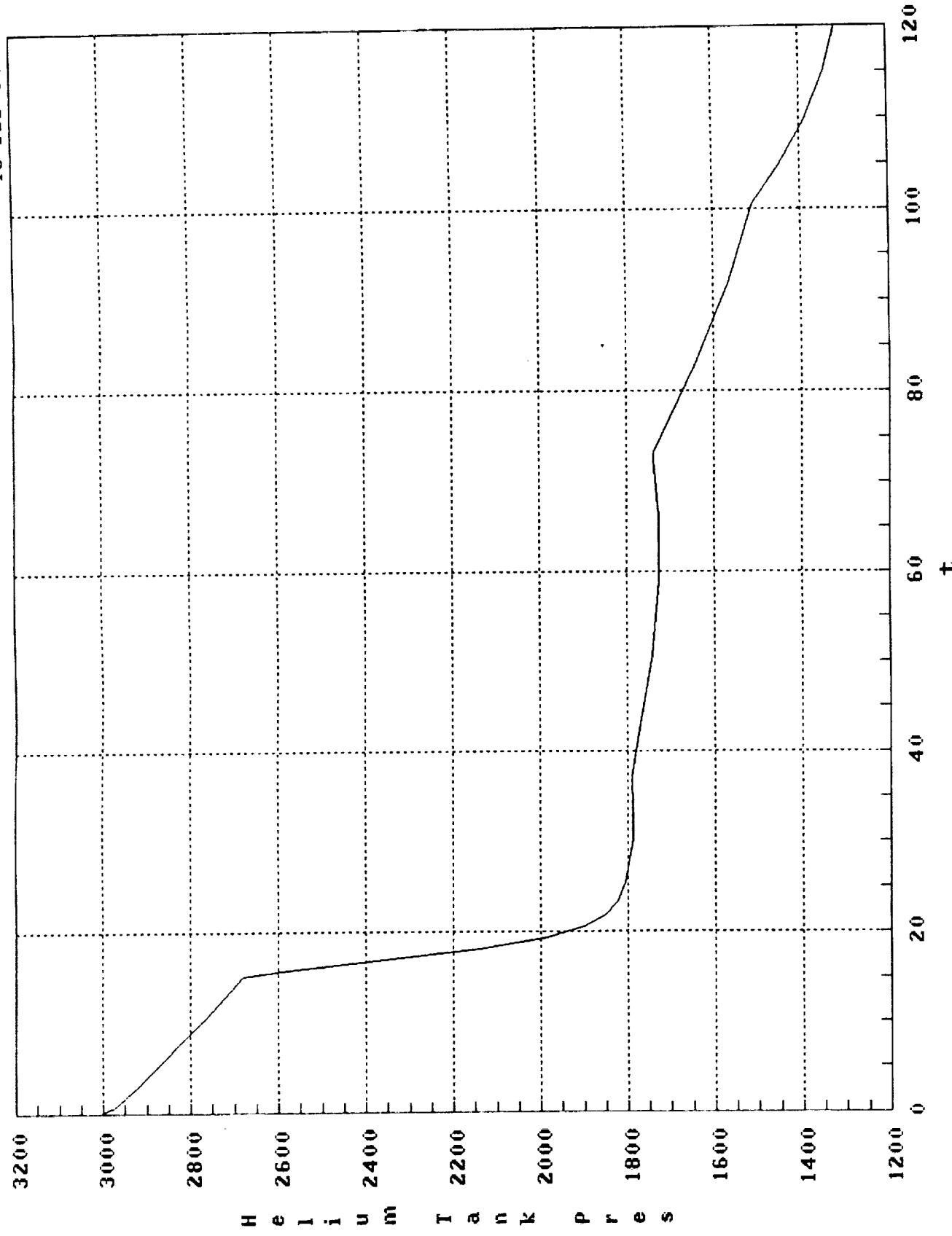
118

16-FEB-90



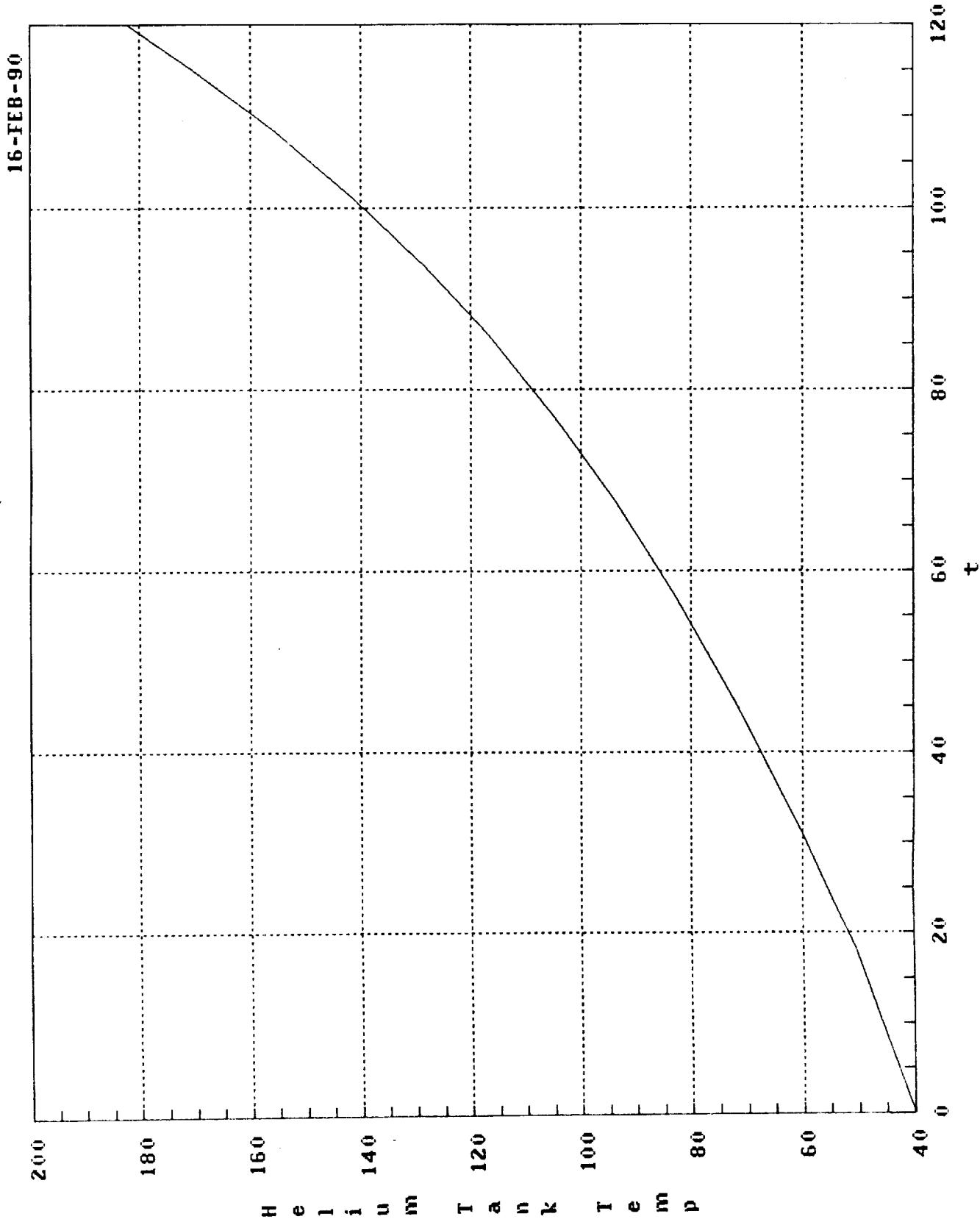
CONFIGURATION 42 FAILED HEATER AT 15 SECONDS

16-FEB-90



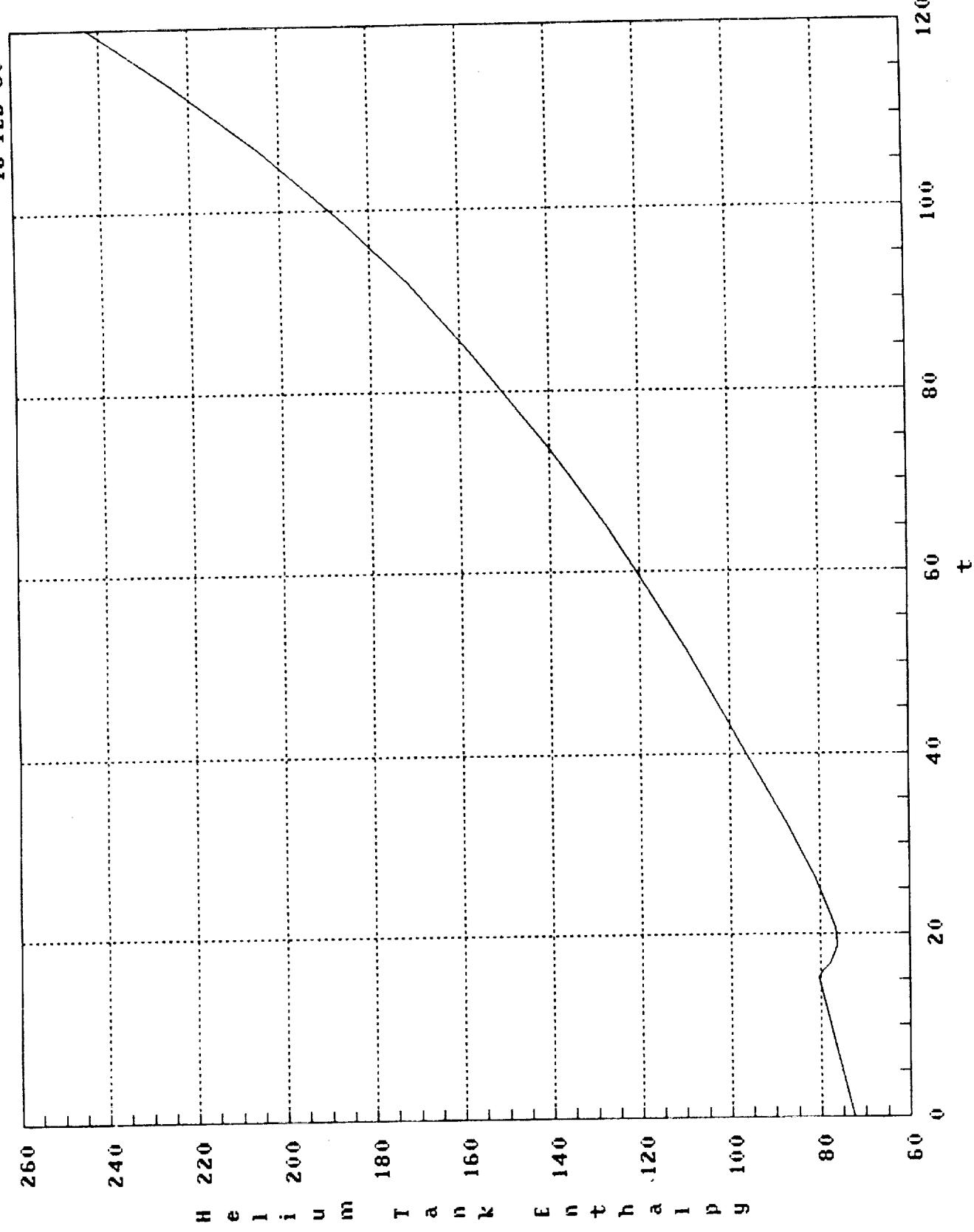
CONFIGURATION 42 FAILED HEATER AT 15 SECONDS

120



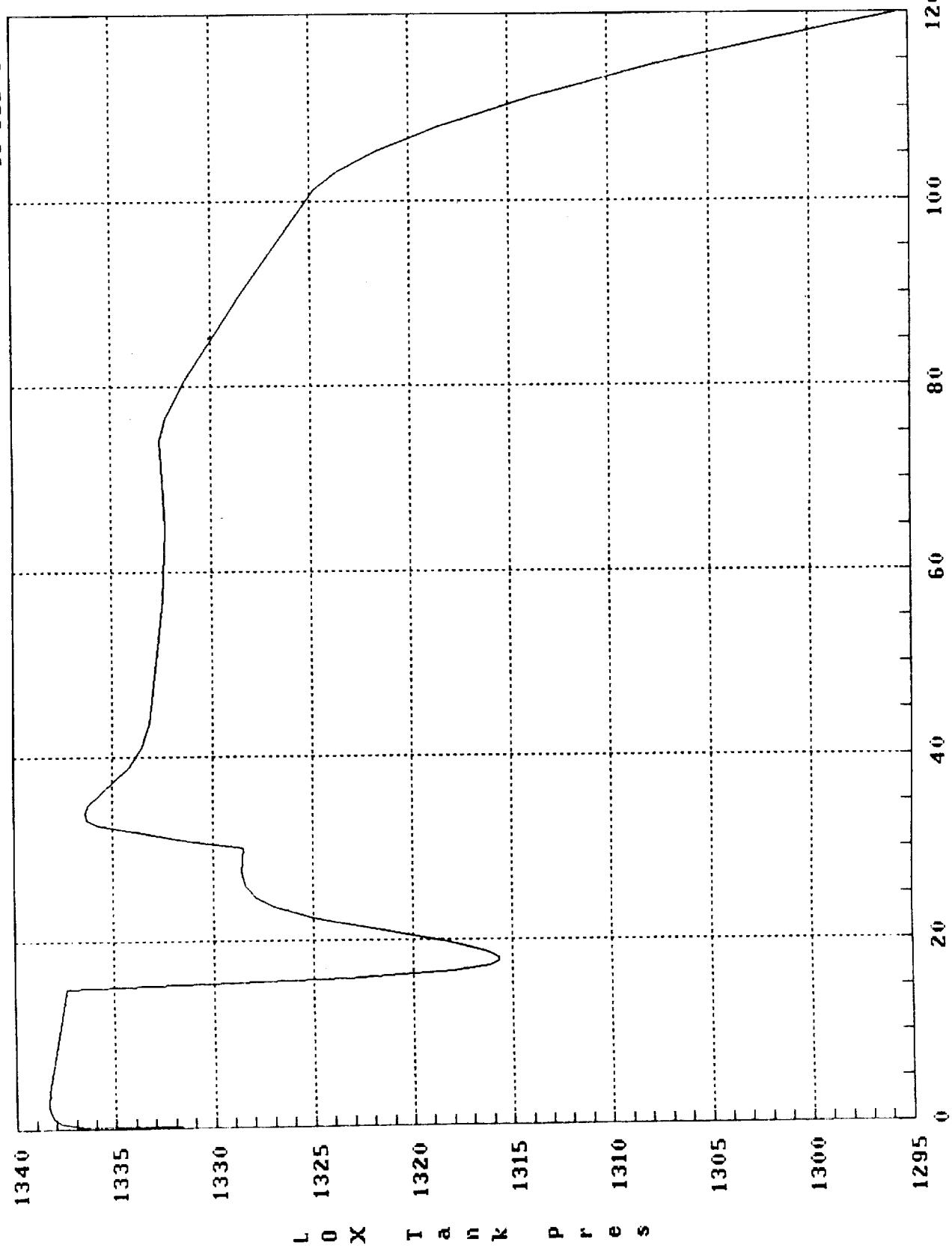
CONFIGURATION 42 FAILED HEATER AT 15 SECONDS

16-FEB-90



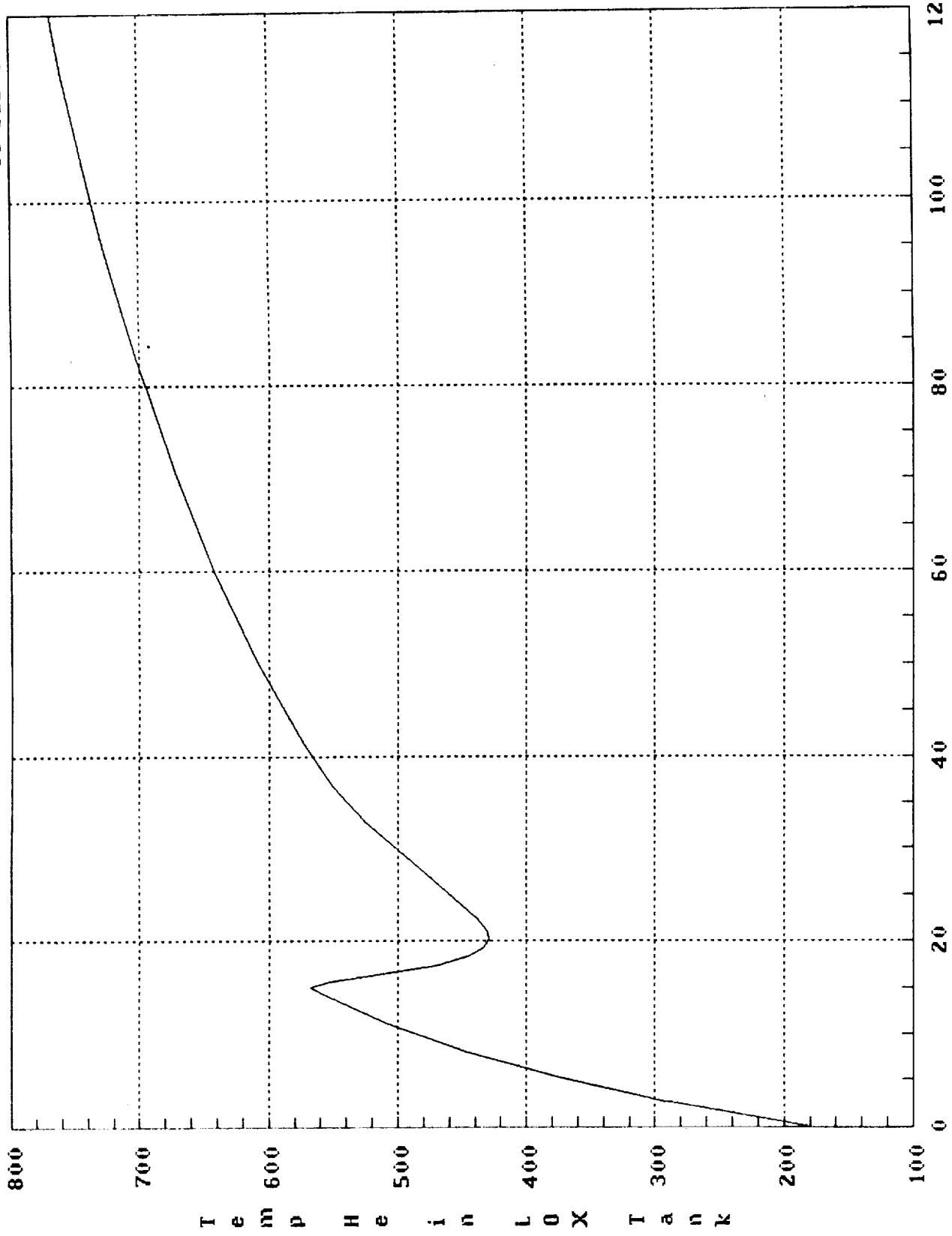
CONFIGURATION 42 FAILED HEATER AT 15 SECONDS

16-FEB-90



CONFIGURATION 42 FAILED HEATER AT 15 SECONDS

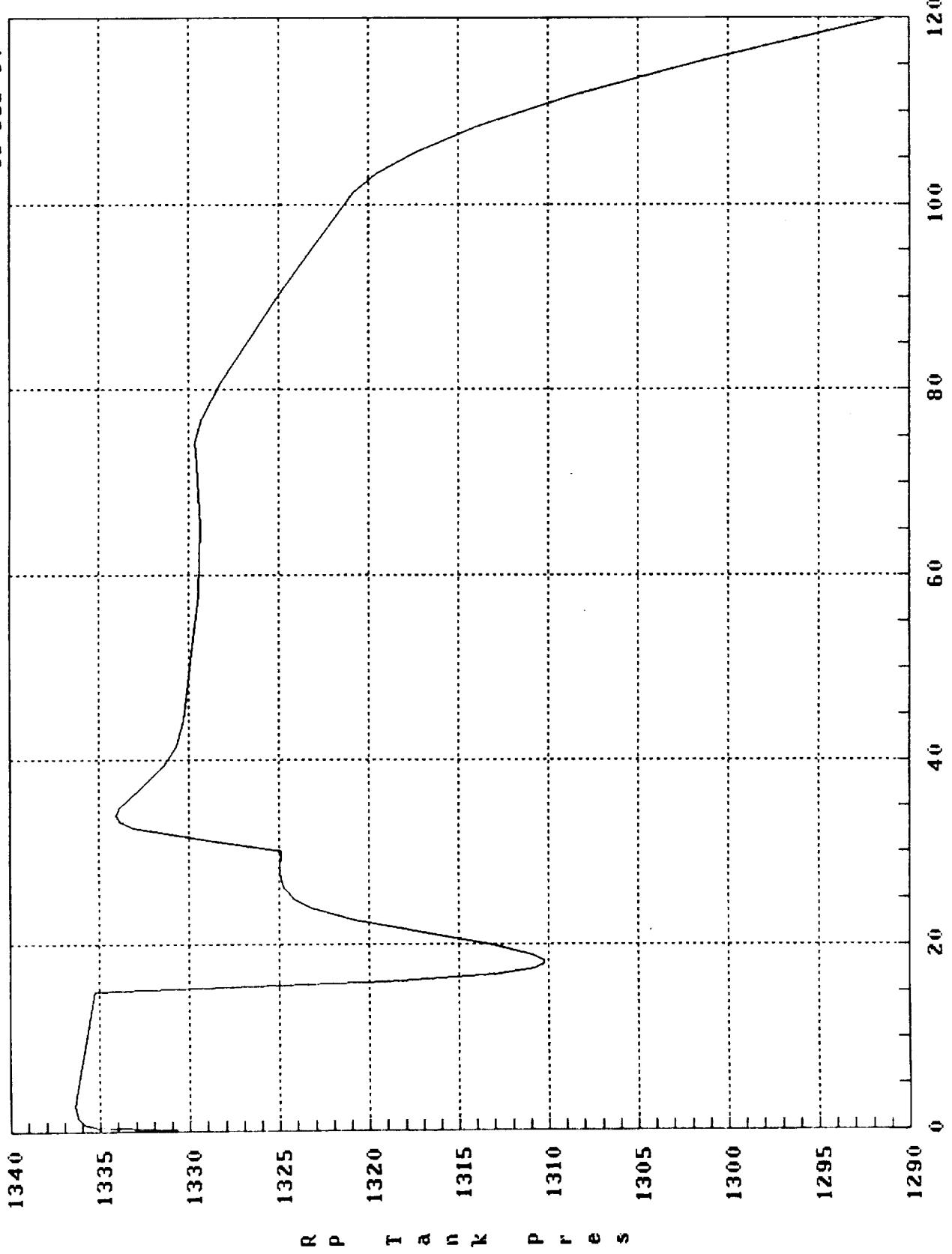
16-FEB-90



CONFIGURATION 42 FAILED HEATER AT 15 SECONDS

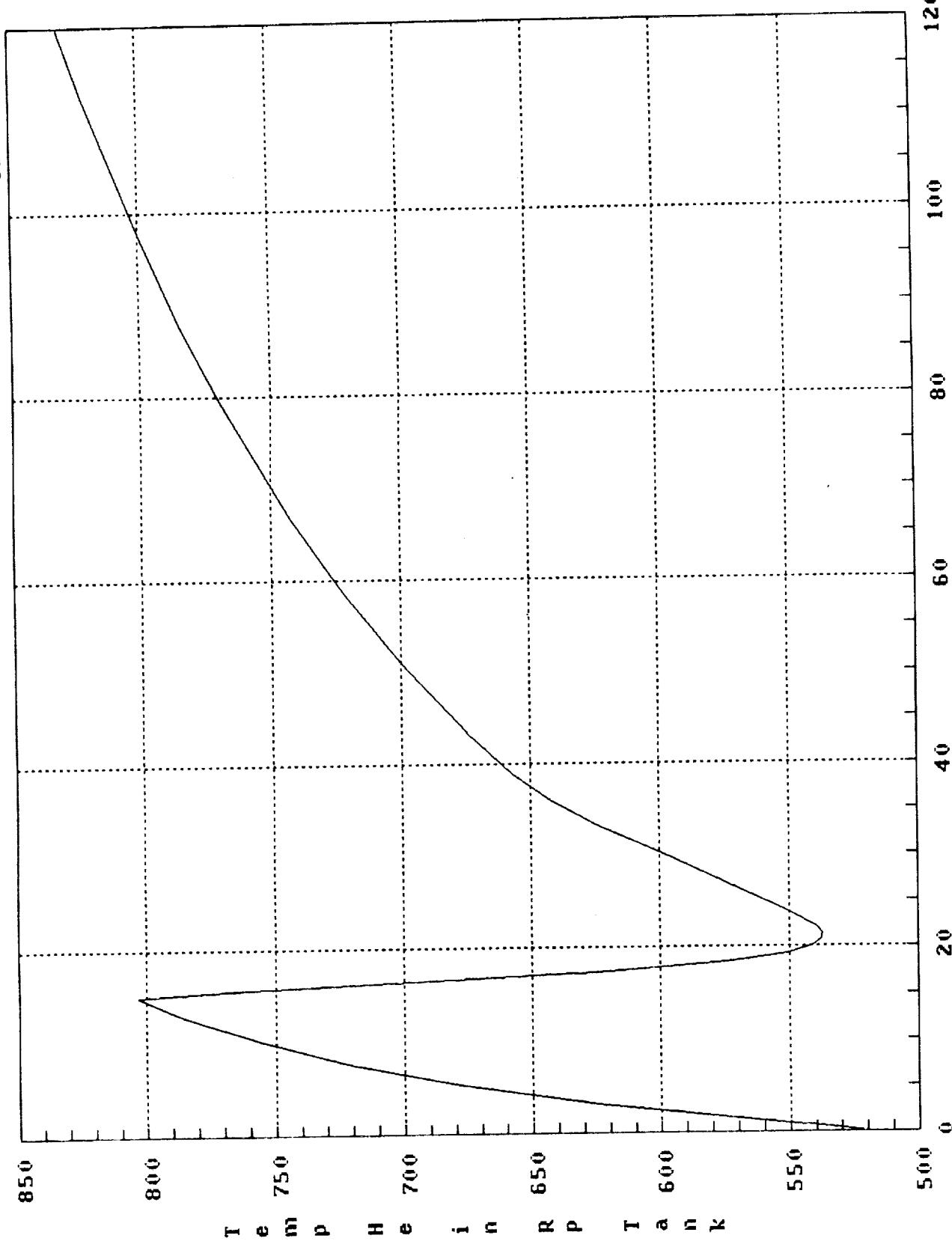
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16-FEB-90



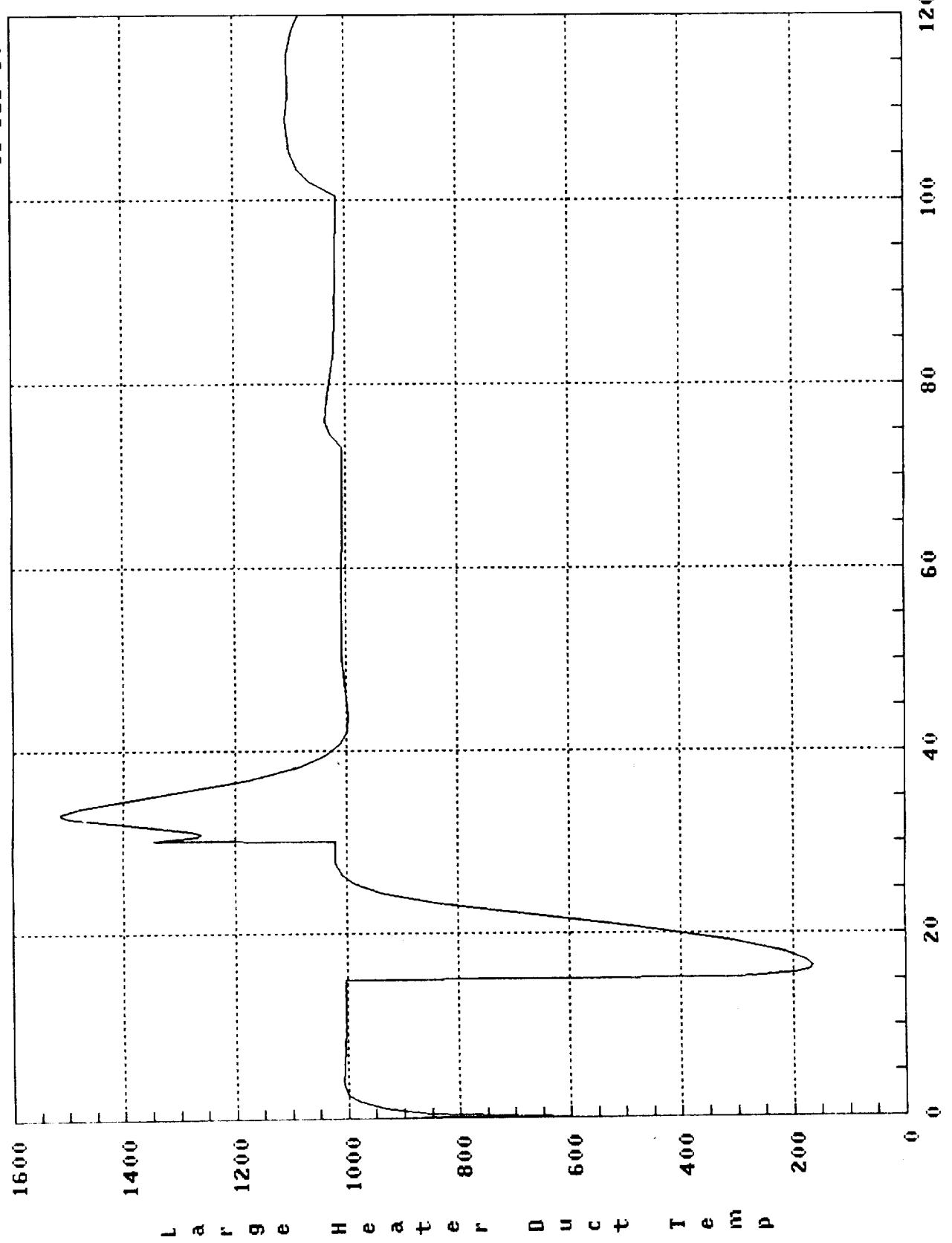
CONFIGURATION 42 FAILED HEATER AT 15 SECONDS

16-FEB-90



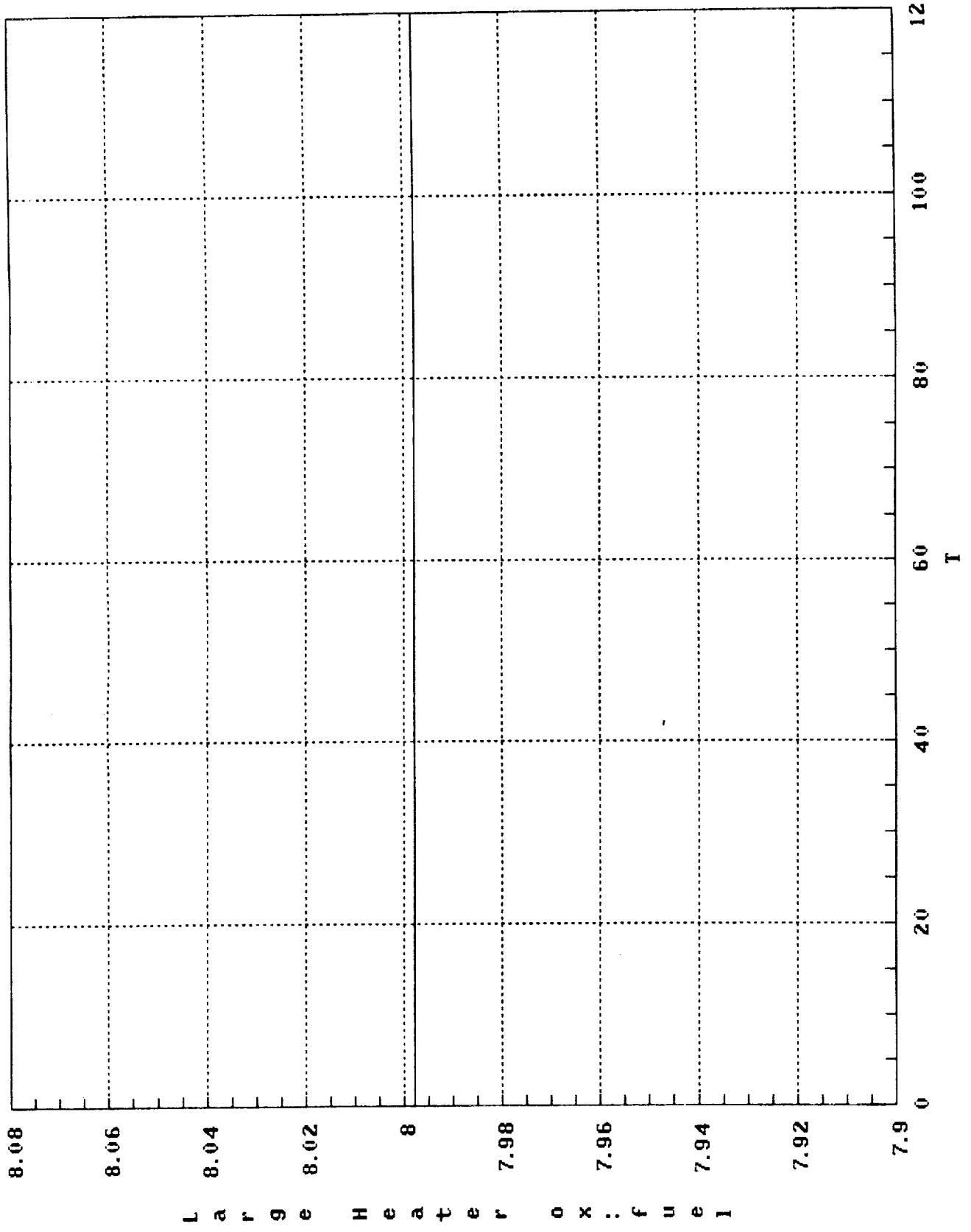
CONFIGURATION 42 FAILED HEATER AT 15 SECONDS

16-FEB-90



CONFIGURATION 42 FAILED HEATER AT 15 SECONDS

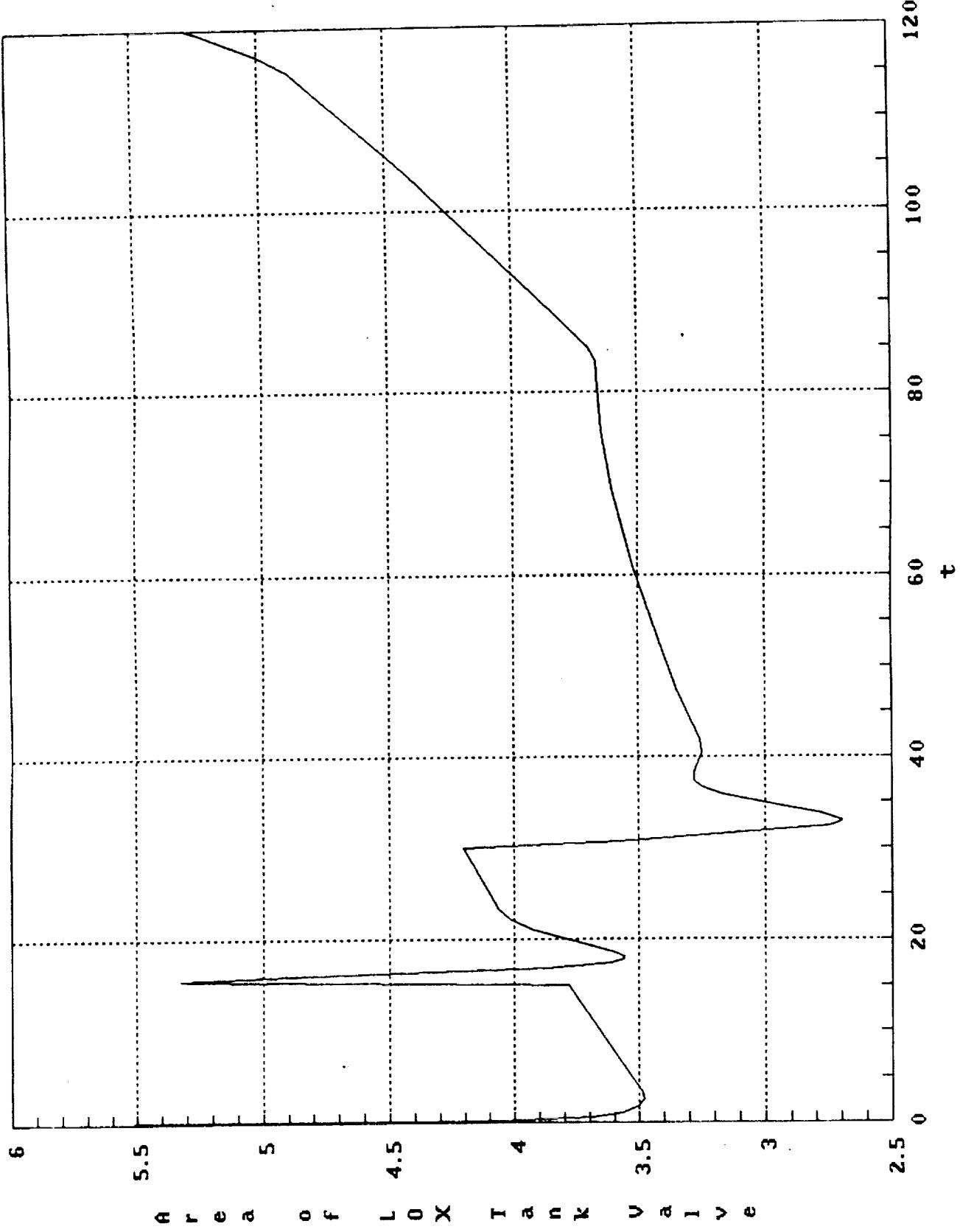
16-FEB-90



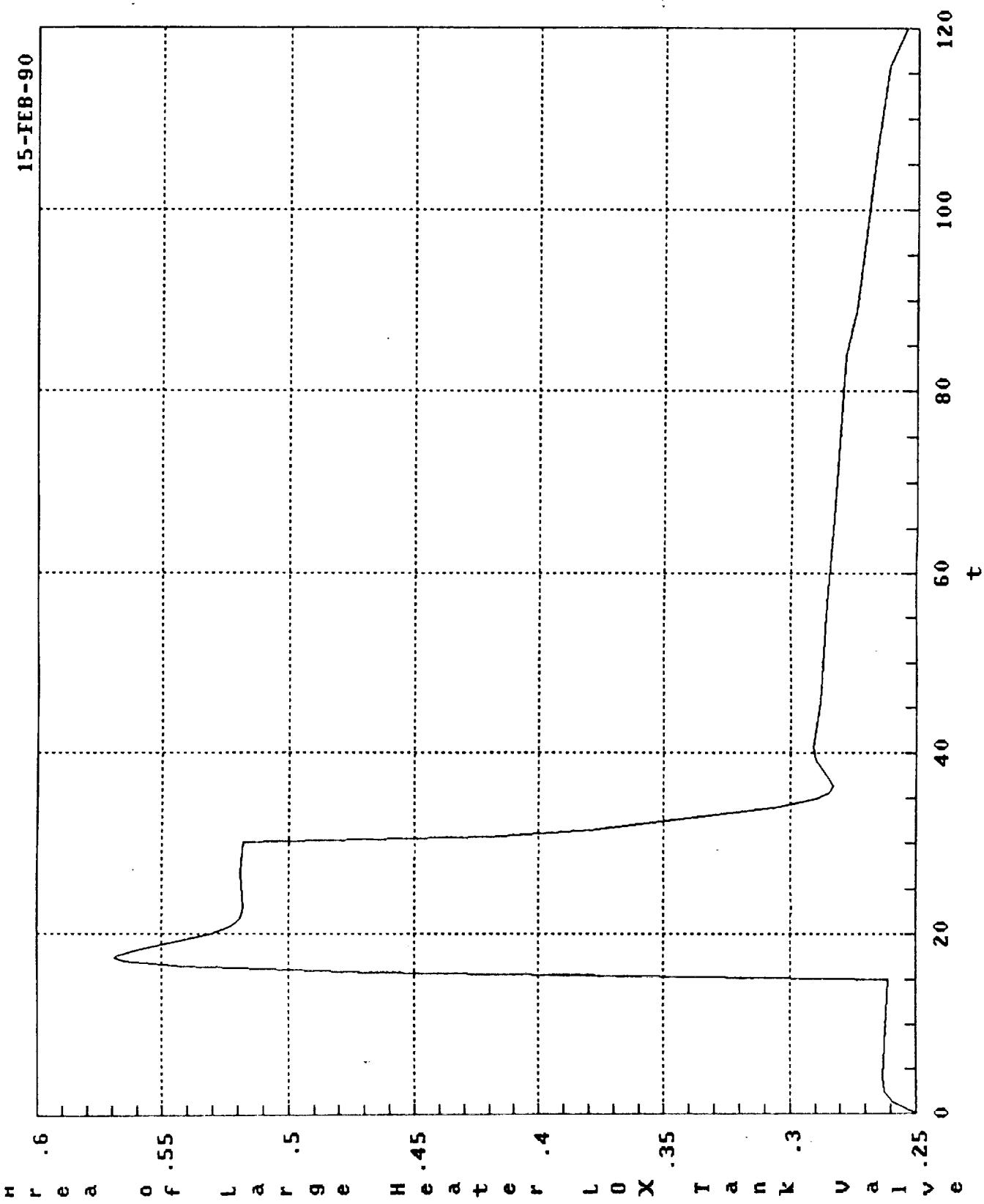
CONFIGURATION 4Z - - FAILURE MODES

- TOTAL HELIUM FLOW DIVIDED 50% PER HEATER PRIOR TO FAILURE
 - LOSS OF 1 PRIMARY HEATER AT $T = 15$ SEC
 - TOTAL HELIUM FLOW RATE THROUGH "GOOD" HEATER AFTER FAILURE
 - HEATER LOX/LH₂ VALVES SET AT 25% AT START-UP
 - HEATER LOX/LH₂ VALVES THROTTLED FROM 50% TO 100% TO ADJUST FOR INCREASED HELIUM FLOW AT FAILURE
 - PERCENTAGE OF TOTAL HELIUM FLOW THROUGH GOOD HEATER
- | | |
|------------------------------|------|
| $T = 0 \rightarrow 15$ SEC | 50% |
| $T = 15 \rightarrow 30$ SEC | 75% |
| $T = 30 \rightarrow 120$ SEC | 100% |

15-FEB-90



CONFIGURATION 42 FAILED HEATER AT 15 SECONDS--THROTTLED HEATER VALUES

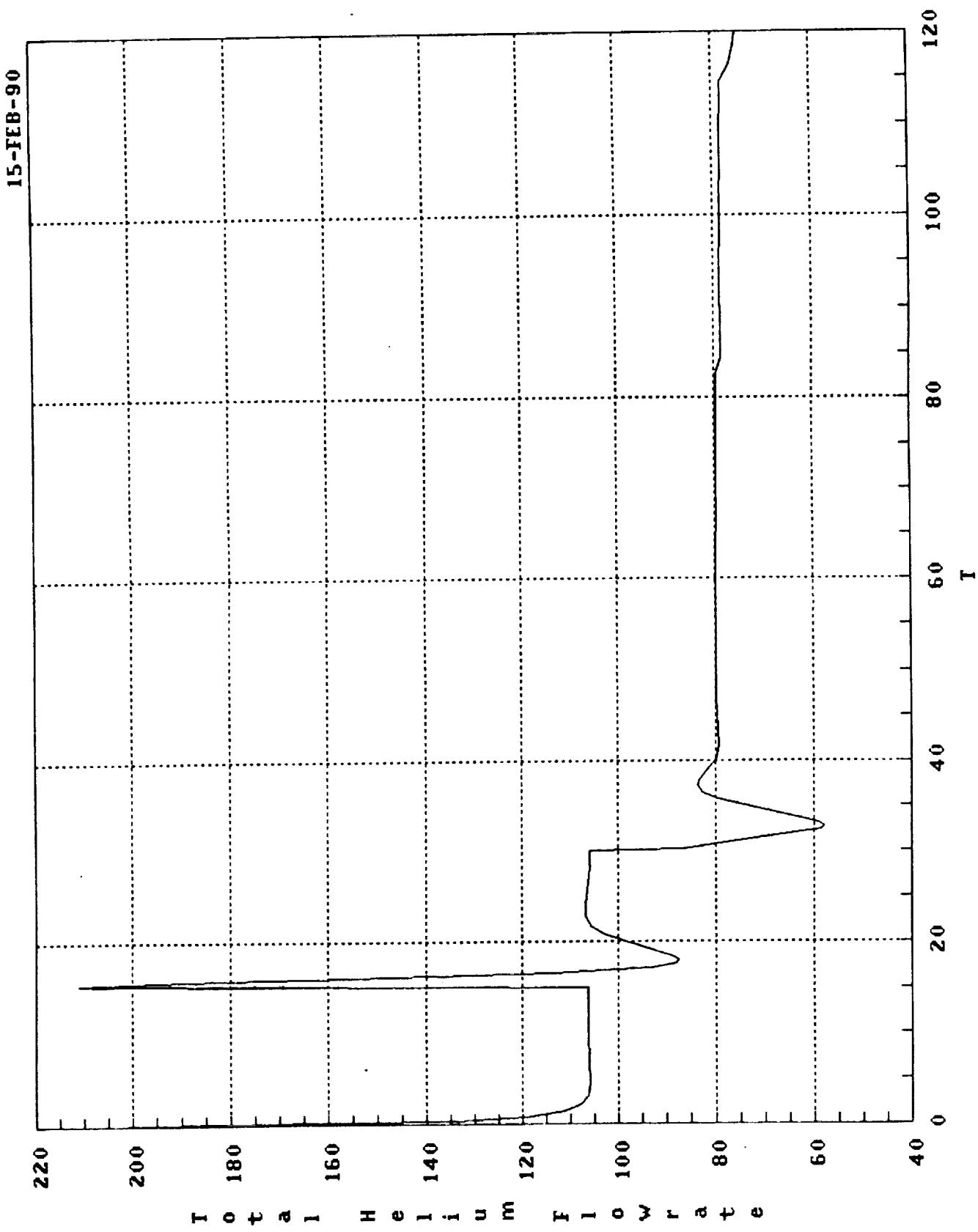


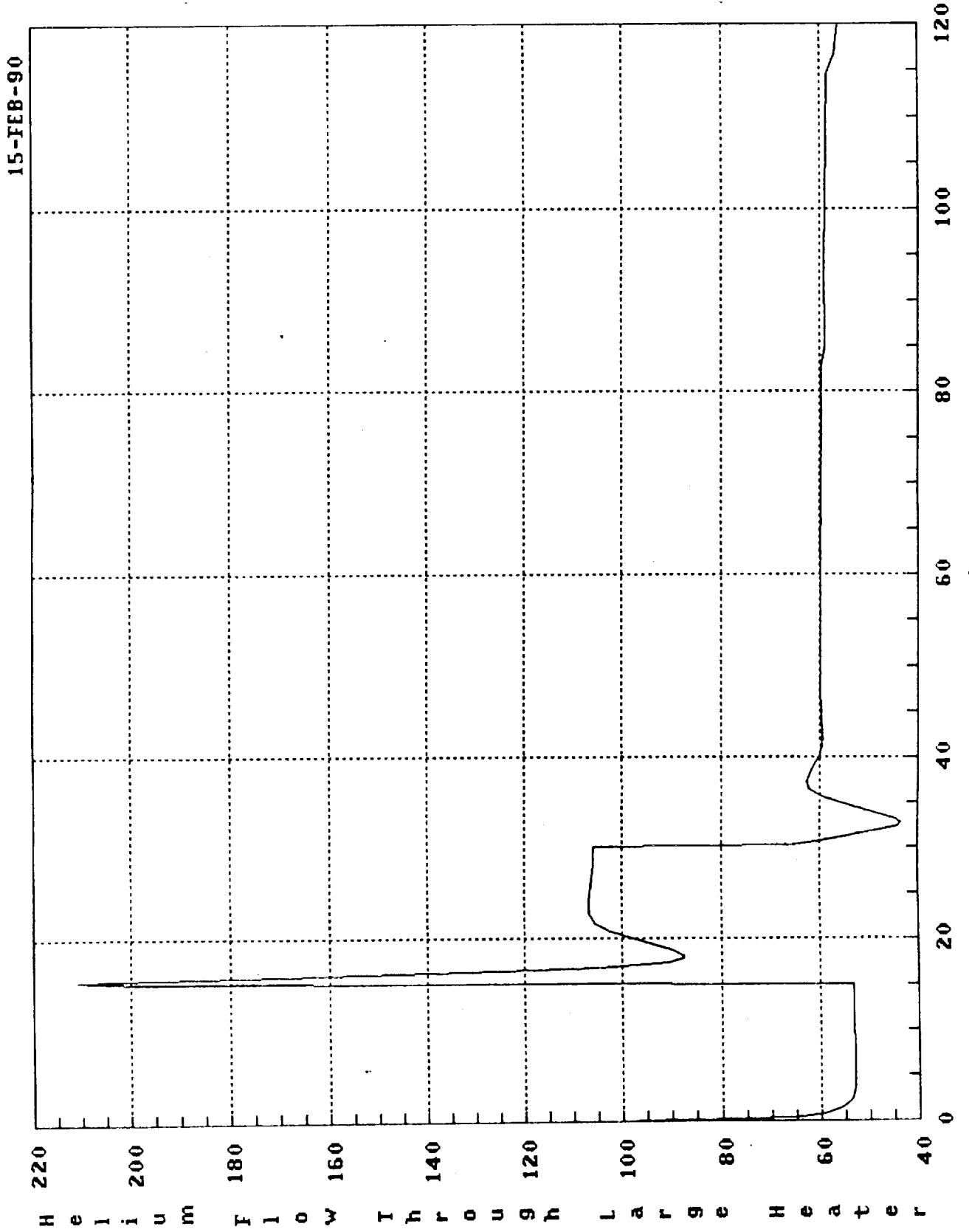
CONFIGURATION 42 FAILED HEATER AT 15 SECONDS--THROTTLED HEATER VALVES

15-FEB-90

CONFIGURATION 42 FAILED HEATER AT 15 SECONDS--THROTTLED HEATER VALUES

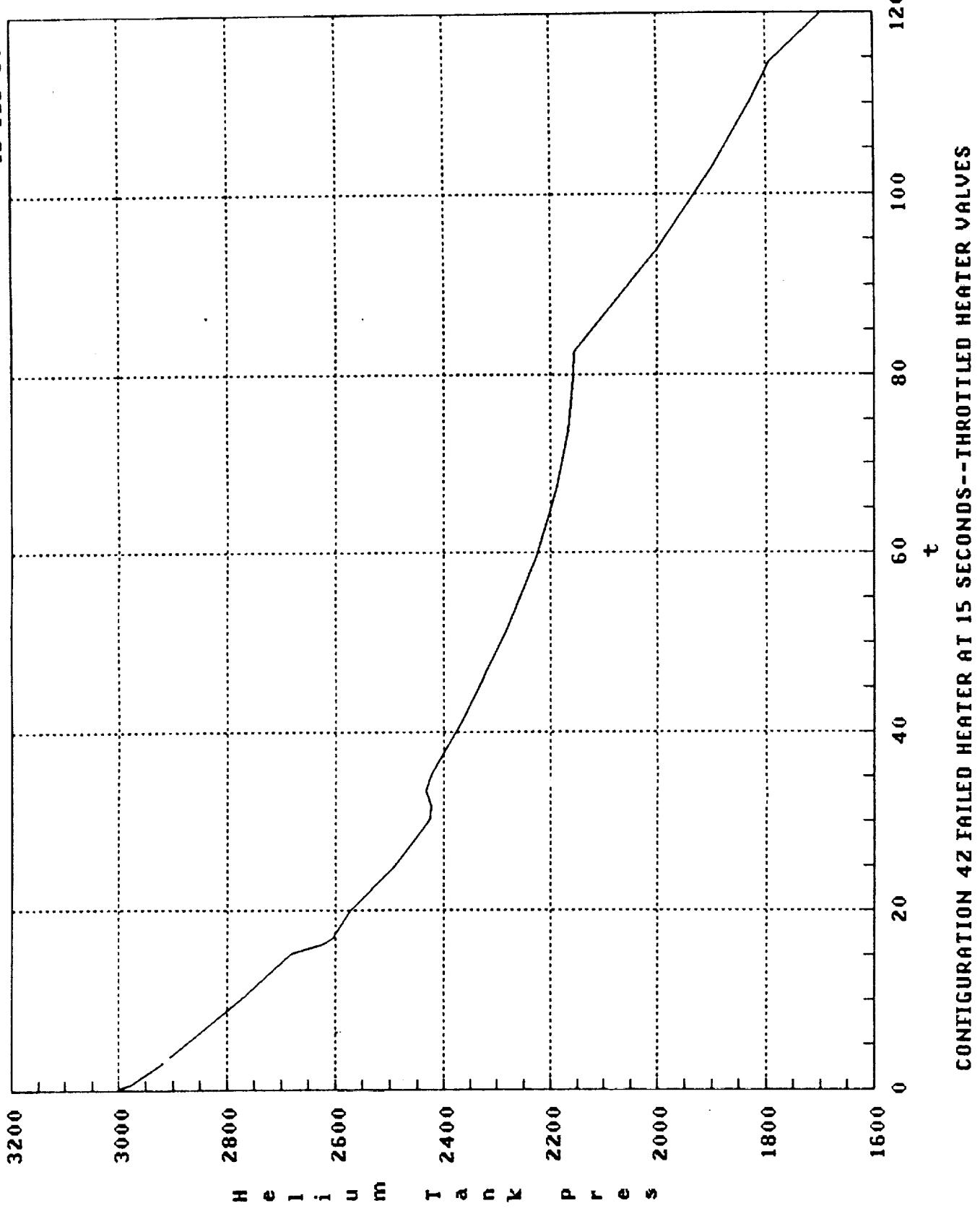
132



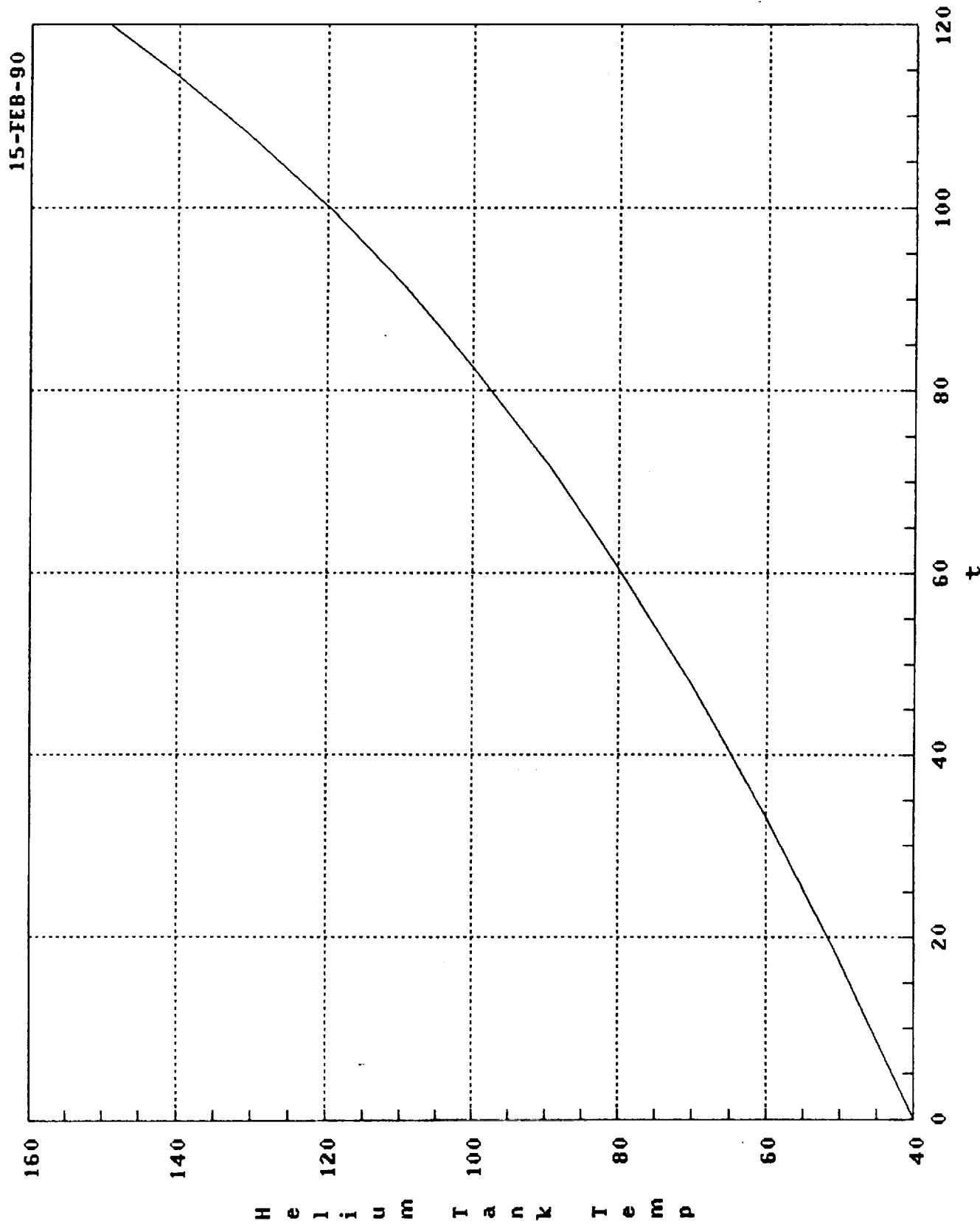


CONFIGURATION 42 FAILED HEATER AT 15 SECONDS--THROTTLED HEATER VALUES

15-FEB-90



CONFIGURATION 42 FAILED HEATER AT 15 SECONDS--THROTTLED HEATER VALUES

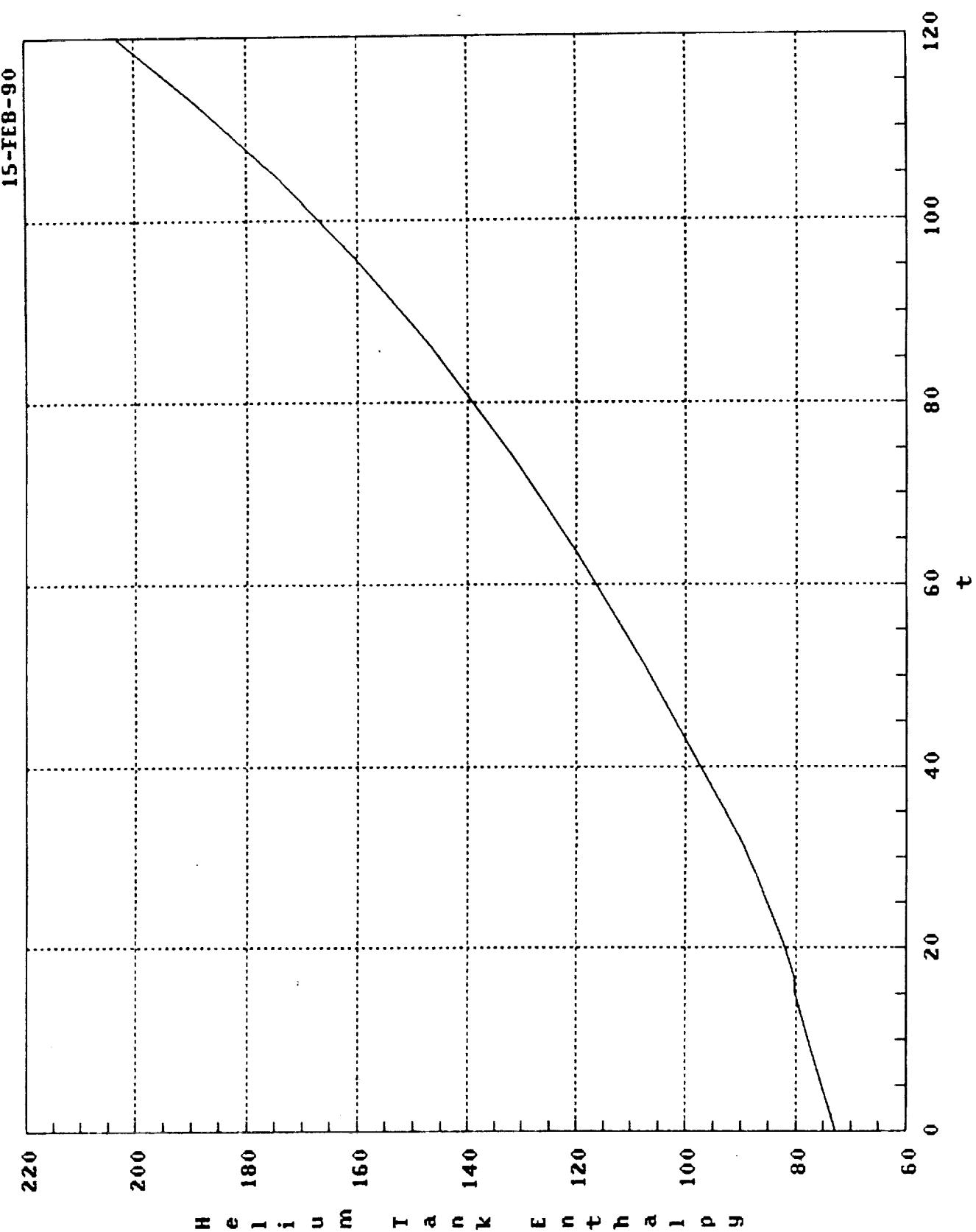


CONFIGURATION 42 FAILED HEATER AT 15 SECONDS--THROTTLED HEATER VALUES

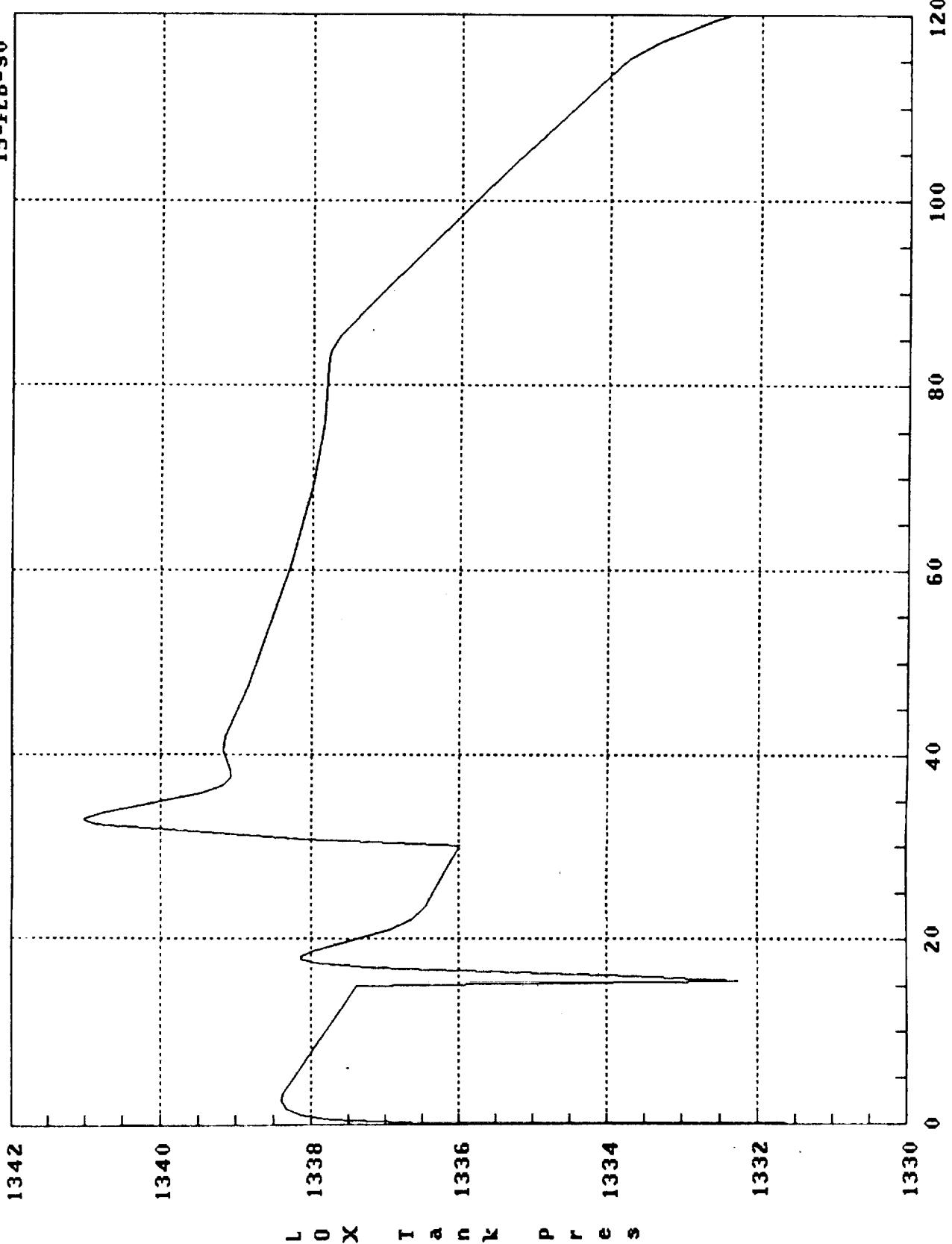
15-FEB-90

CONFIGURATION 42 FAILED HEATER AT 15 SECONDS--THROTTLED HEATER VALUES

136

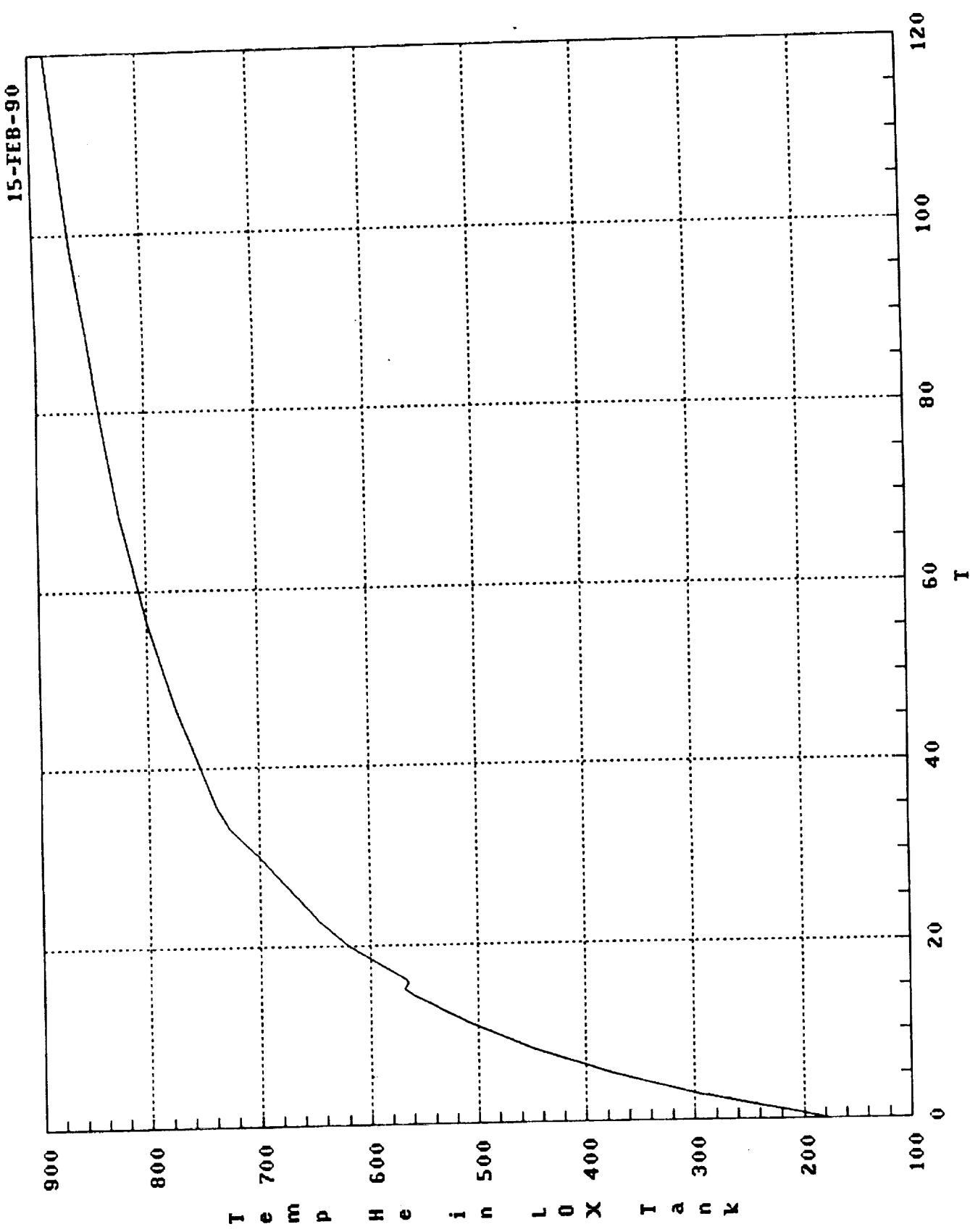


15-FEB-90

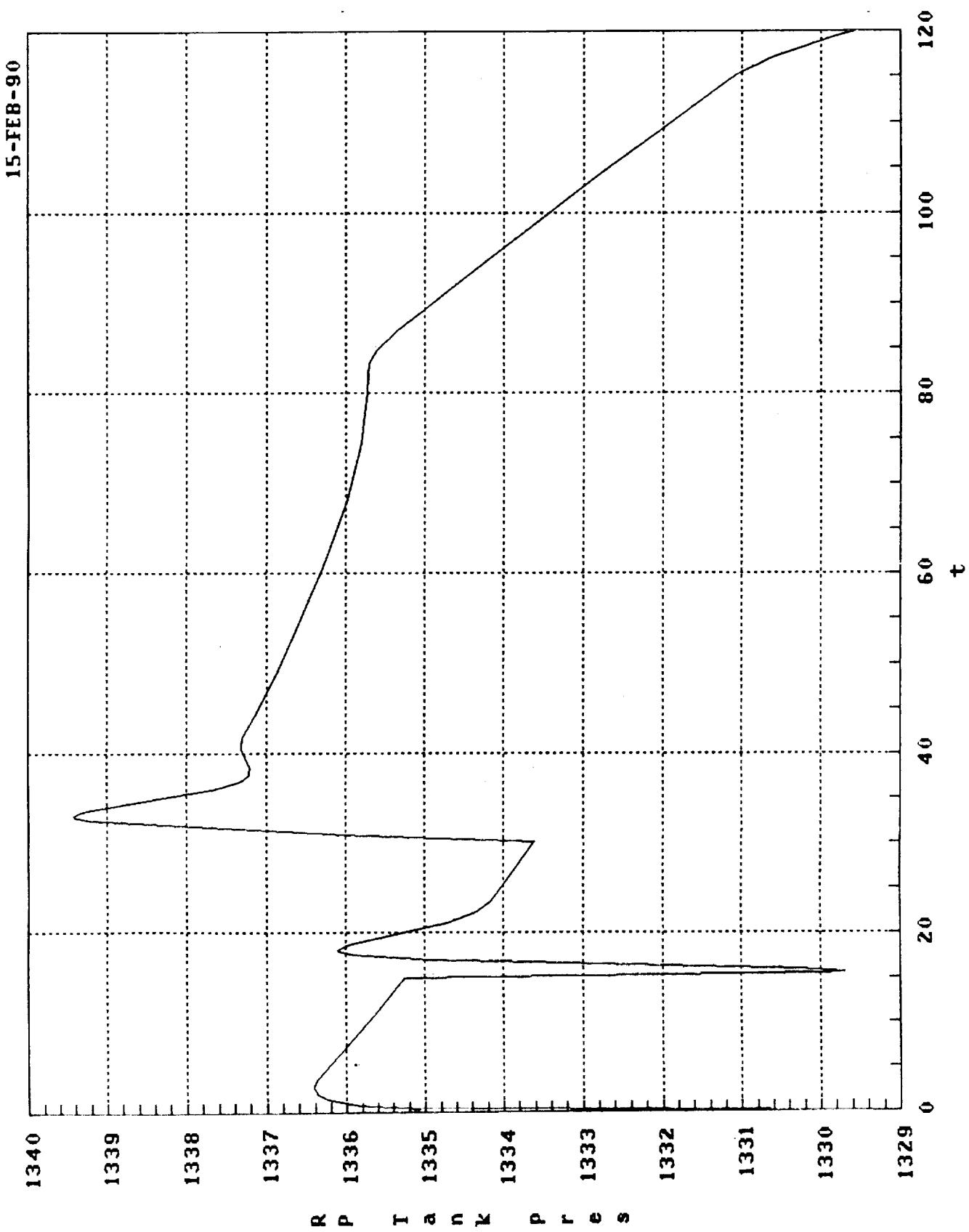


CONFIGURATION 42 FAILED HEATER AT 15 SECONDS--THROTTLED HEATER VALVES

CONFIGURATION 42 FAILED HEATER AT 15 SECONDS--THROTTLED HEATER VALUES



15-FEB-90

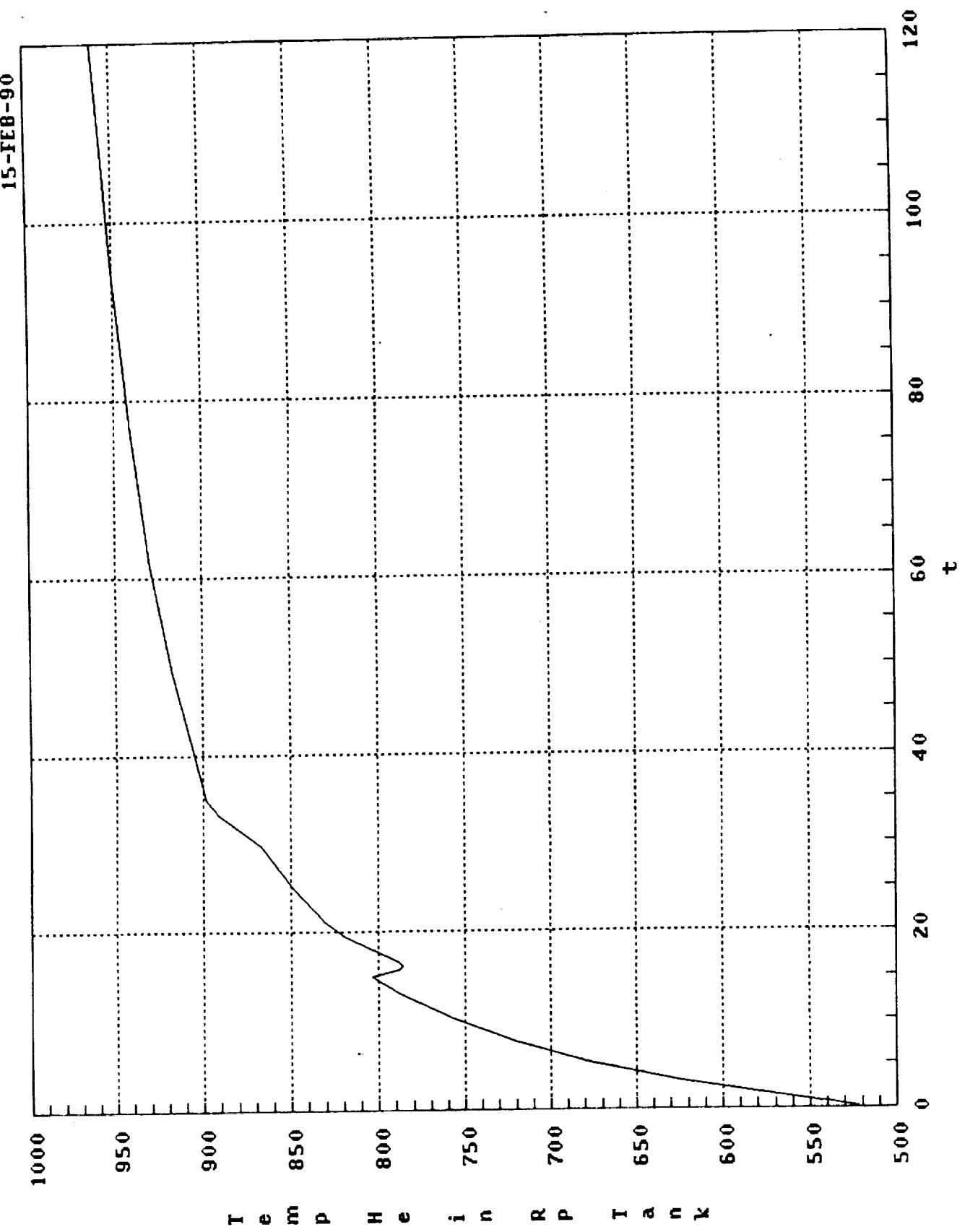


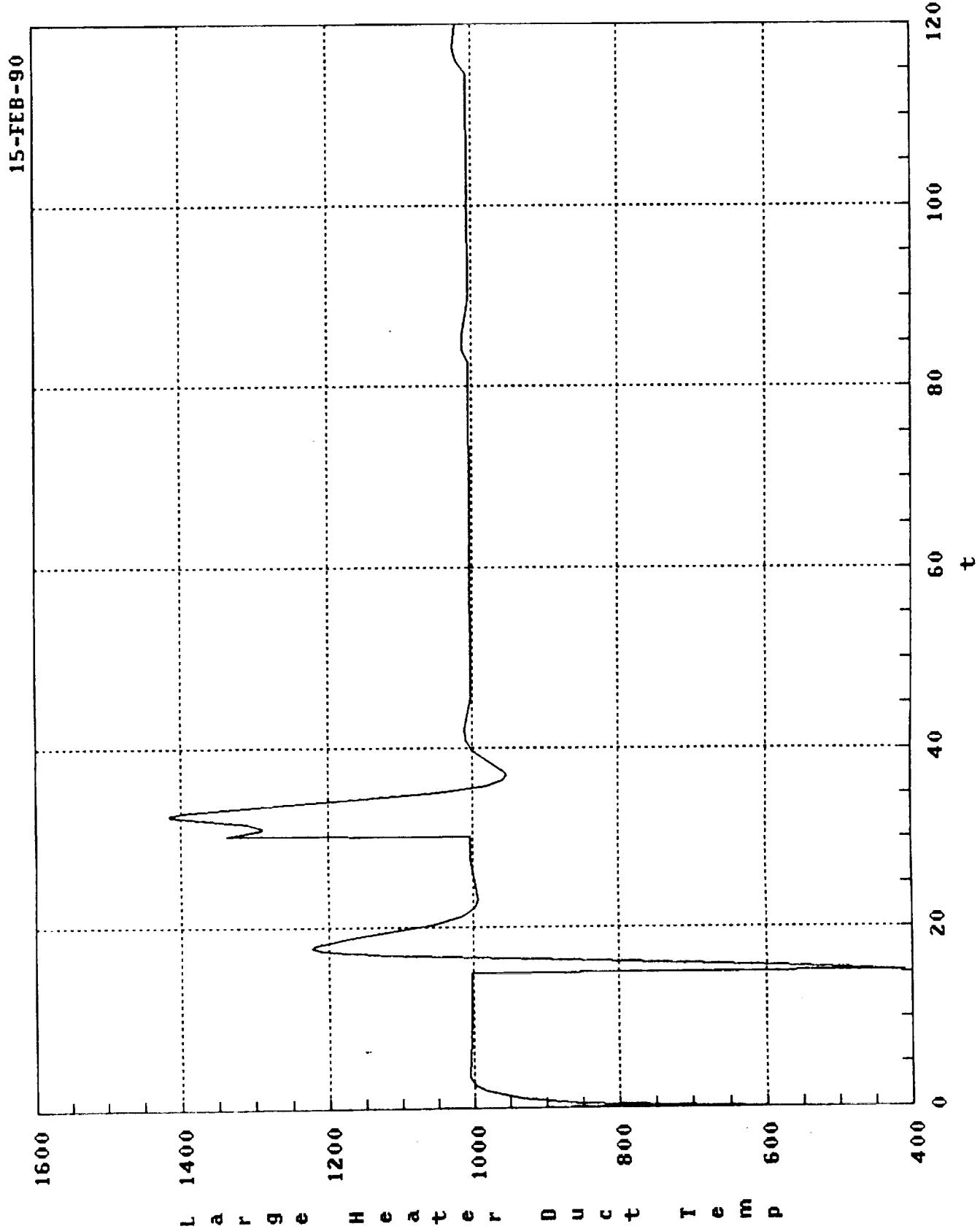
CONFIGURATION 42 FAILED HEATER AT 15 SECONDS--THROTTLED HEATER VALUES

15-FEB-90

CONFIGURATION 4Z FAILED HEATER AT 15 SECONDS--THROTTLED HEATER VALVES

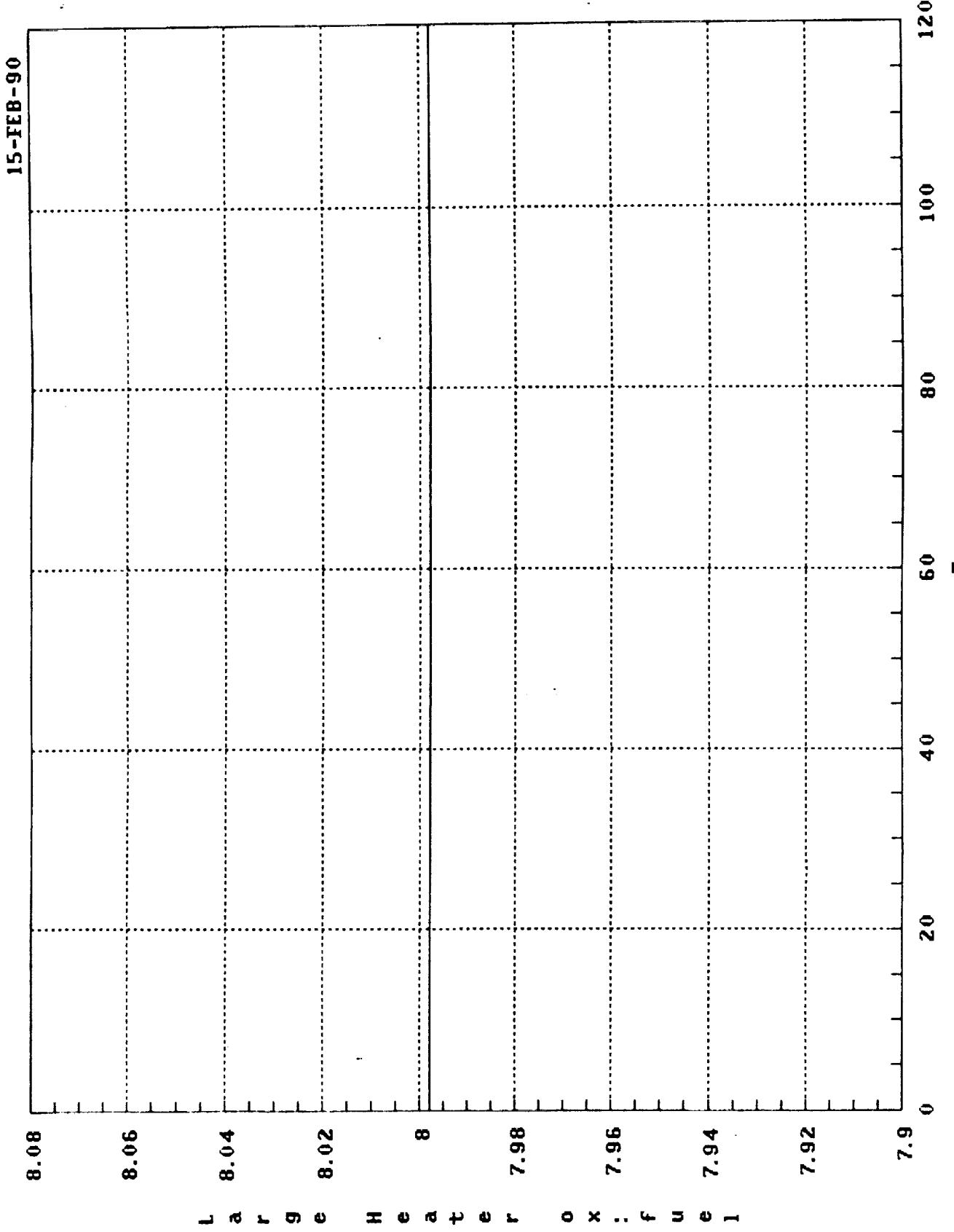
140





CONFIGURATION 42 FAILED HEATER AT 15 SECONDS--THROTTLED HEATER VALUES

15-FEB-90



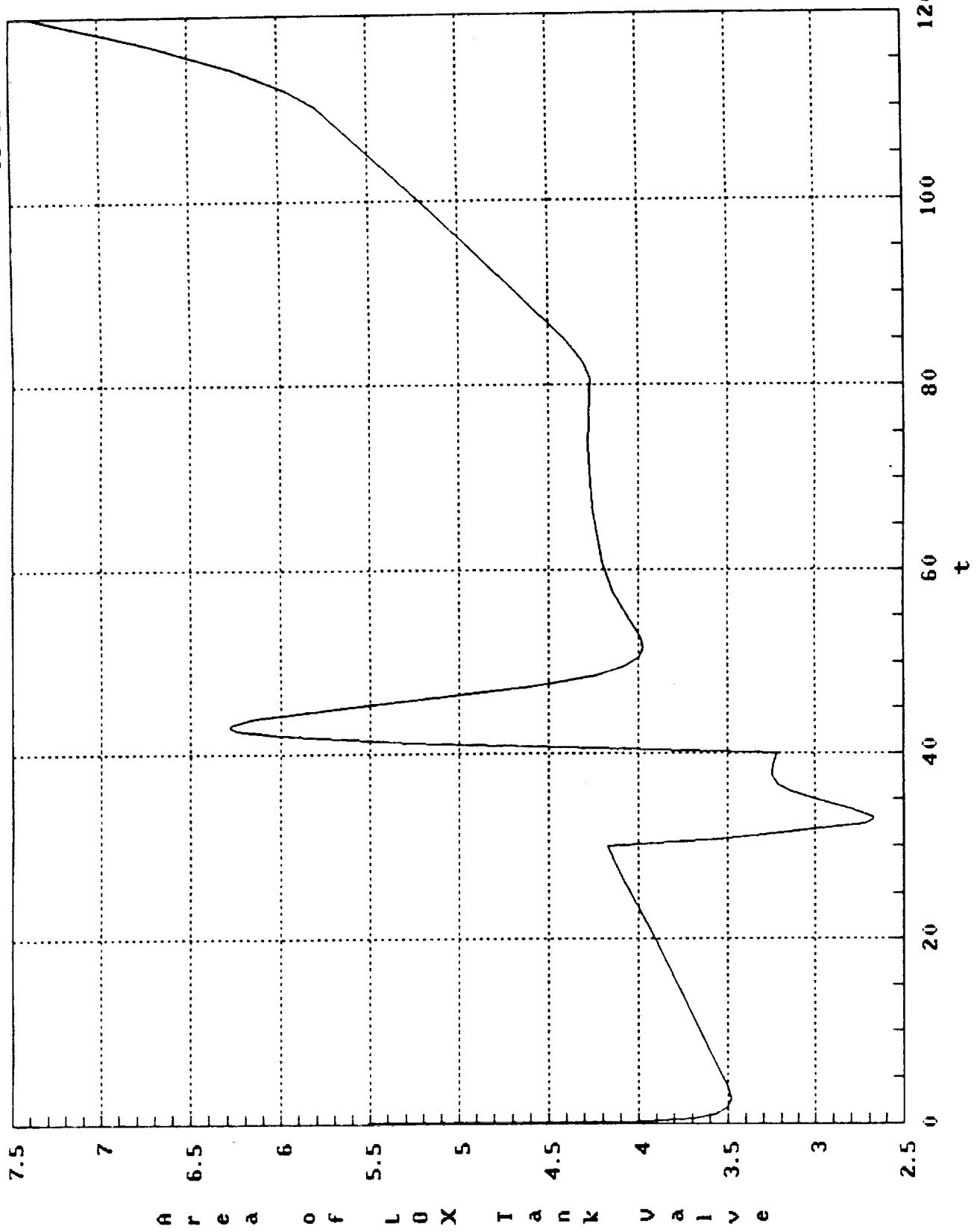
CONFIGURATION 42 FAILED HEATER AT 15 SECONDS-- THROTTLED HEATER VALUES

CONFIGURATION 4Z - - FAILURE MODES

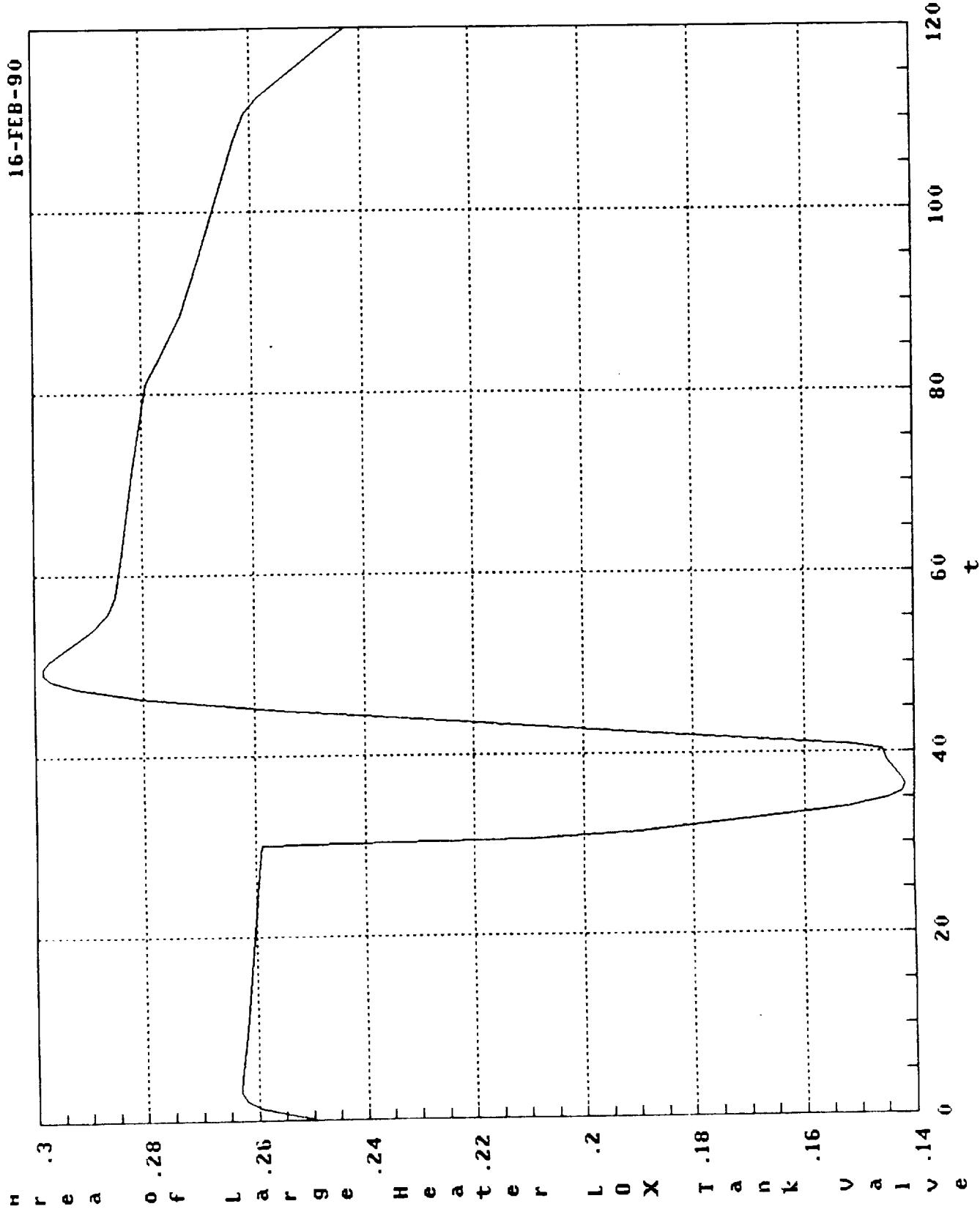
- TOTAL HELIUM FLOW DIVIDED 50% PER PRIMARY HEATER PRIOR TO FAILURE
- LOSS OF 1 PRIMARY HEATER AT T = 15 SEC
- TOTAL HELIUM FLOW RATE THROUGH "GOOD" HEATER AFTER FAILURE
- HEATER LOX/LH₂ VALVES SET AT 25% AT START-UP
- HEATER LOX/LH₂ VALVES NOT ADJUSTED FOR "FAILURE" MODE
- PERCENTAGE OF TOTAL HELIUM FLOW RATE THROUGH GOOD HEATER

T = 0 → 30 SEC	50%
T = 30 → 40 SEC	37.5%
T = 40 → 120 SEC	75%

16-FEB-90

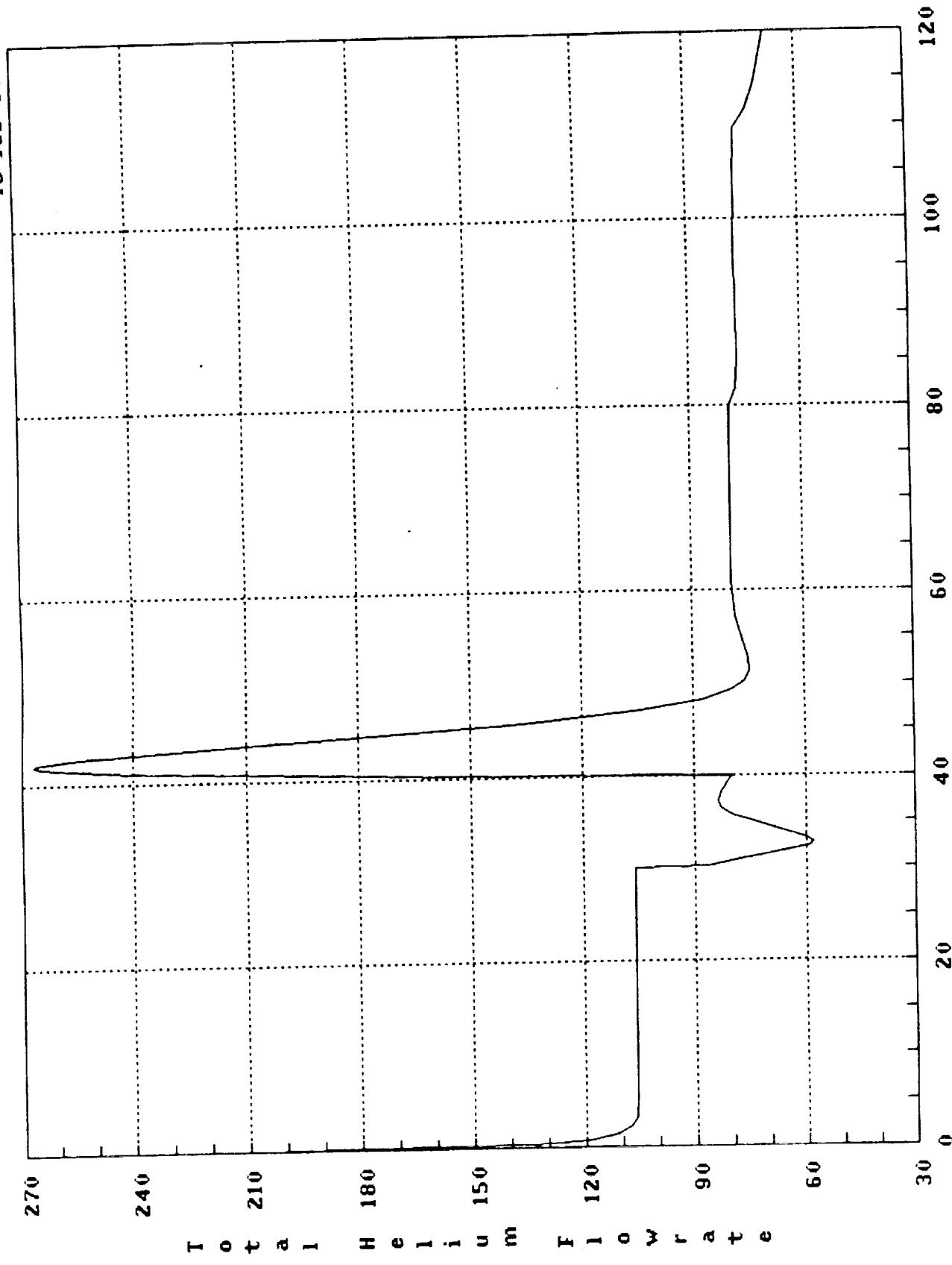


CONFIGURATION 42 FAILED HEATER AT 40 SECONDS



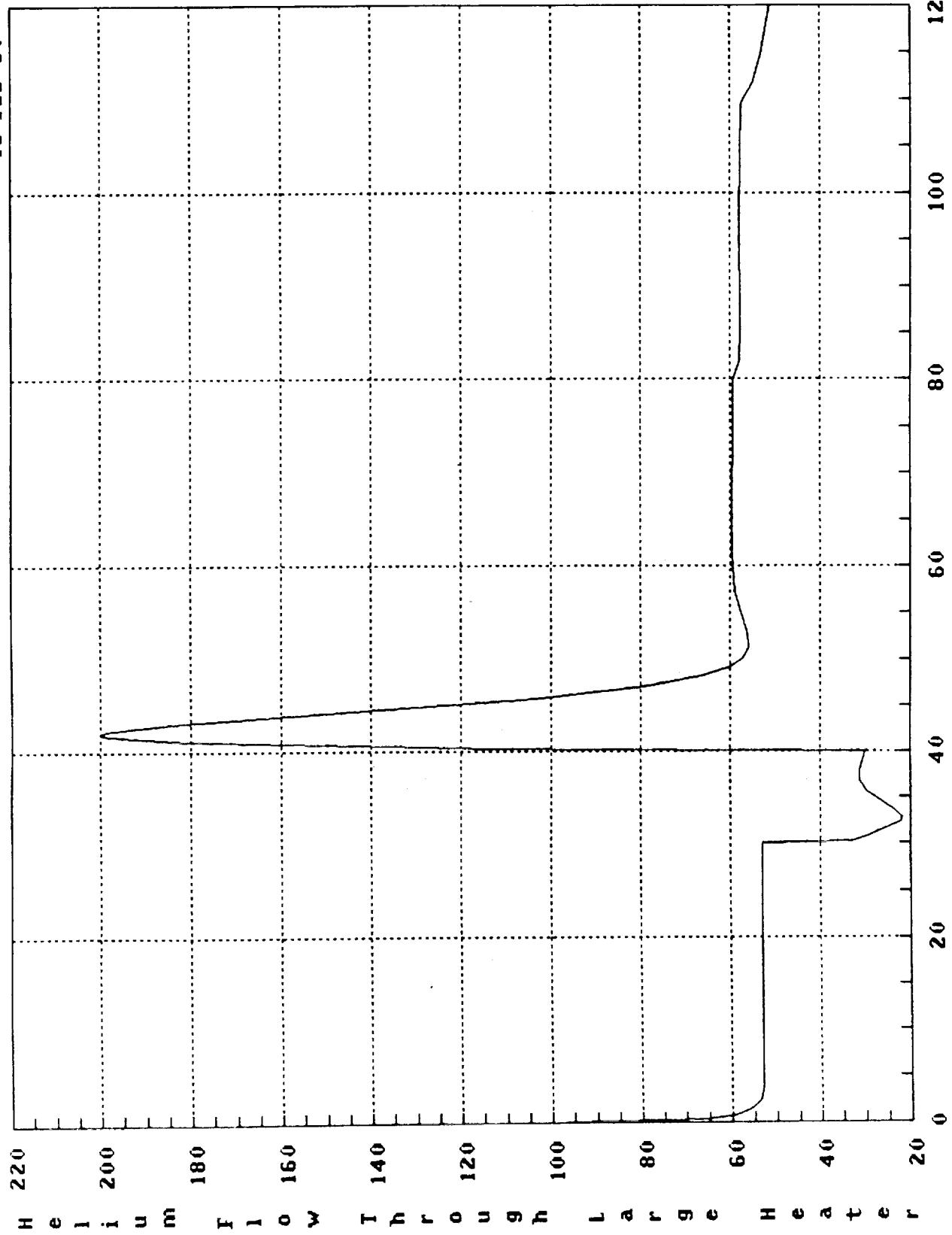
CONFIGURATION 4Z FAILED HEATER AT 40 SECONDS

16-FEB-90



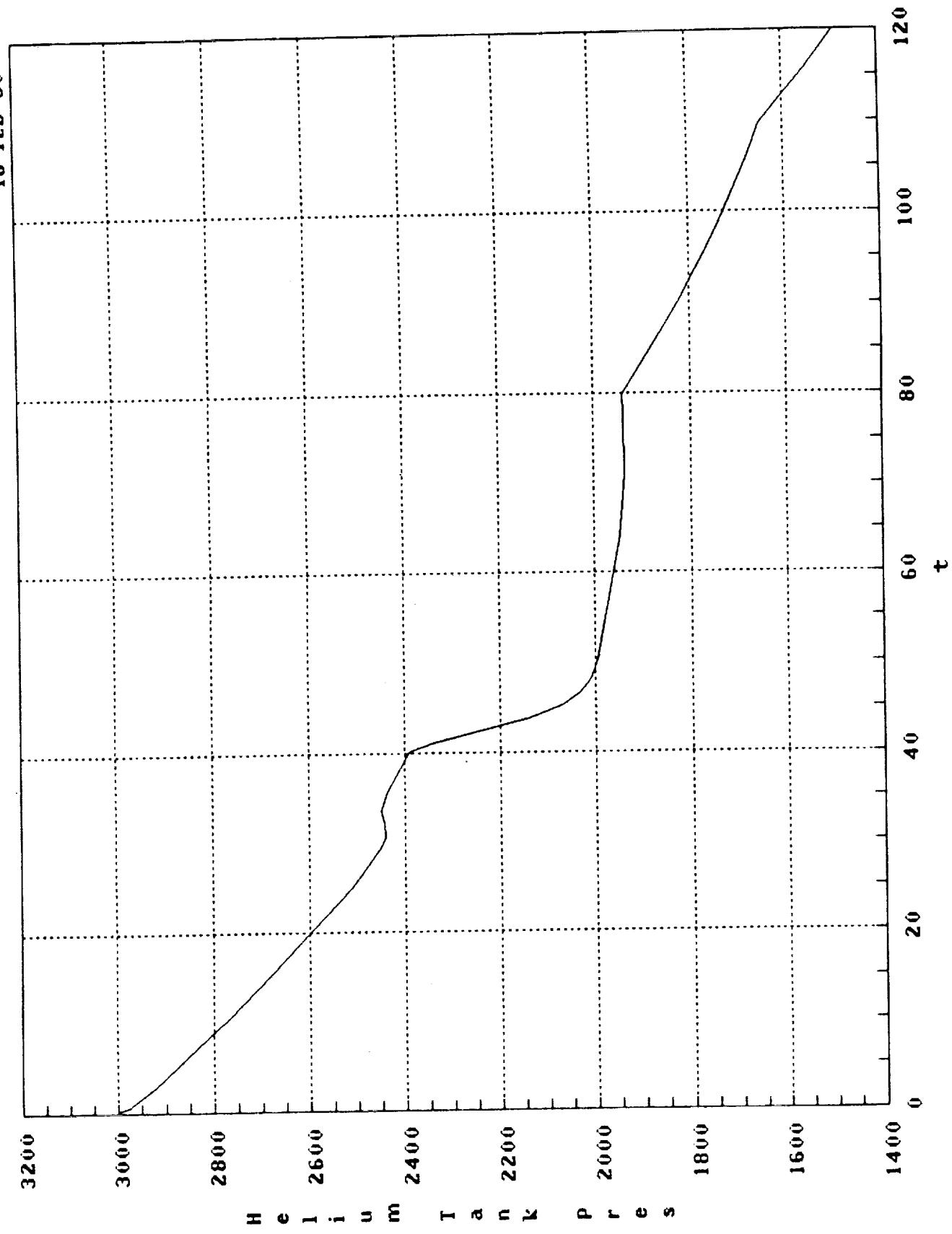
CONFIGURATION 4Z FAILED HEATER AT 40 SECONDS

16-FEB-90

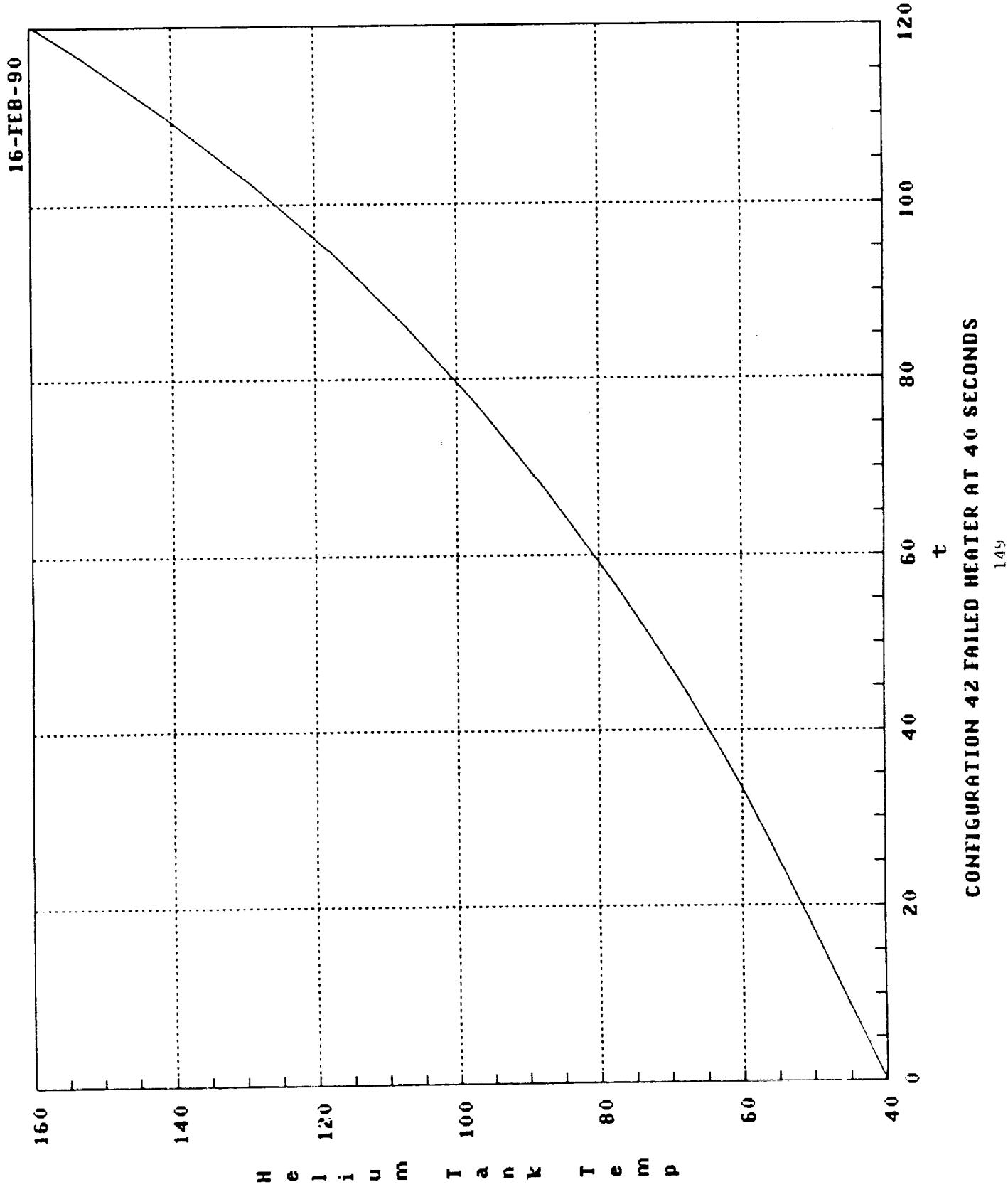


CONFIGURATION 4Z FAILED HEATER AT 40 SECONDS

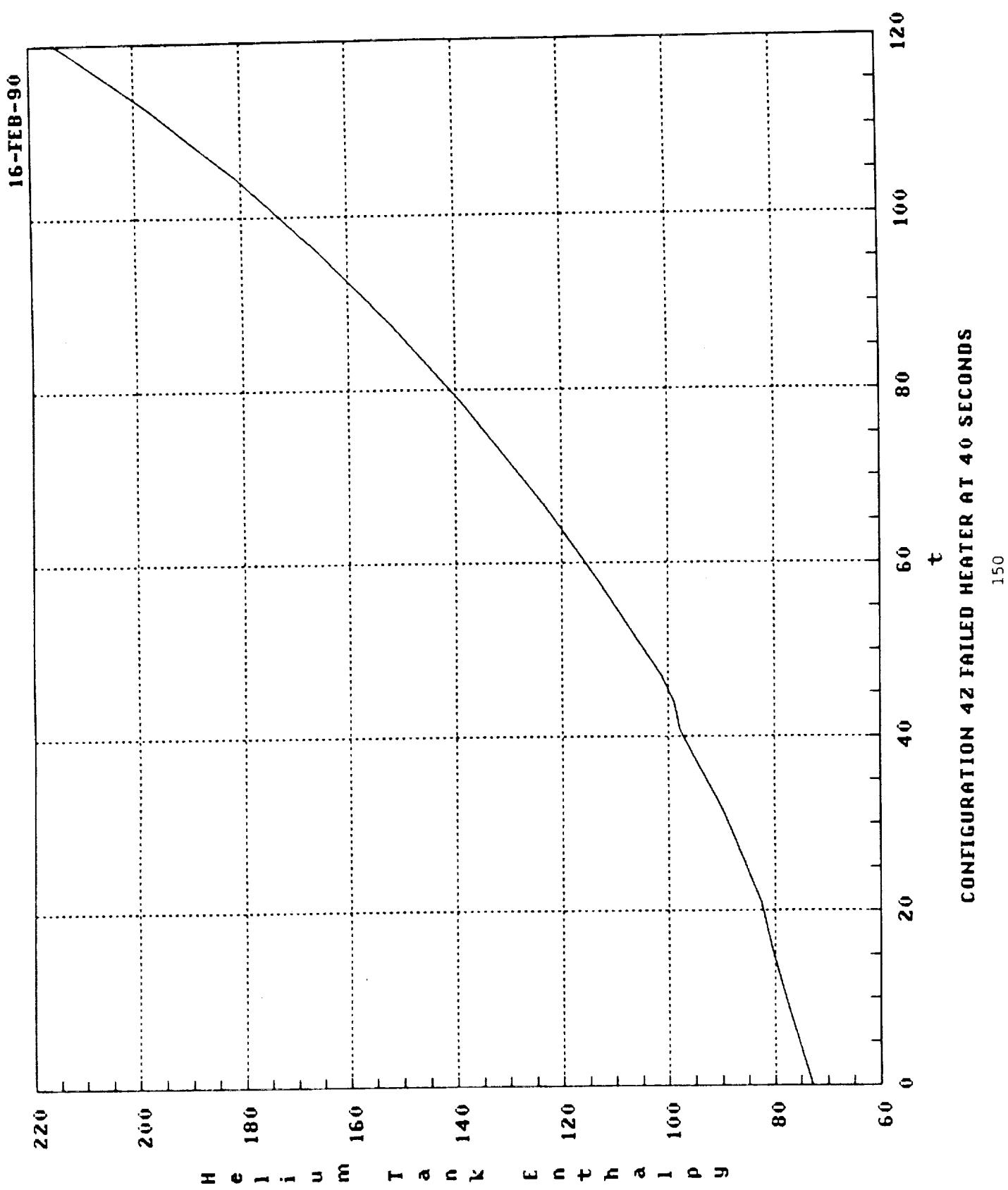
16-FEB-90



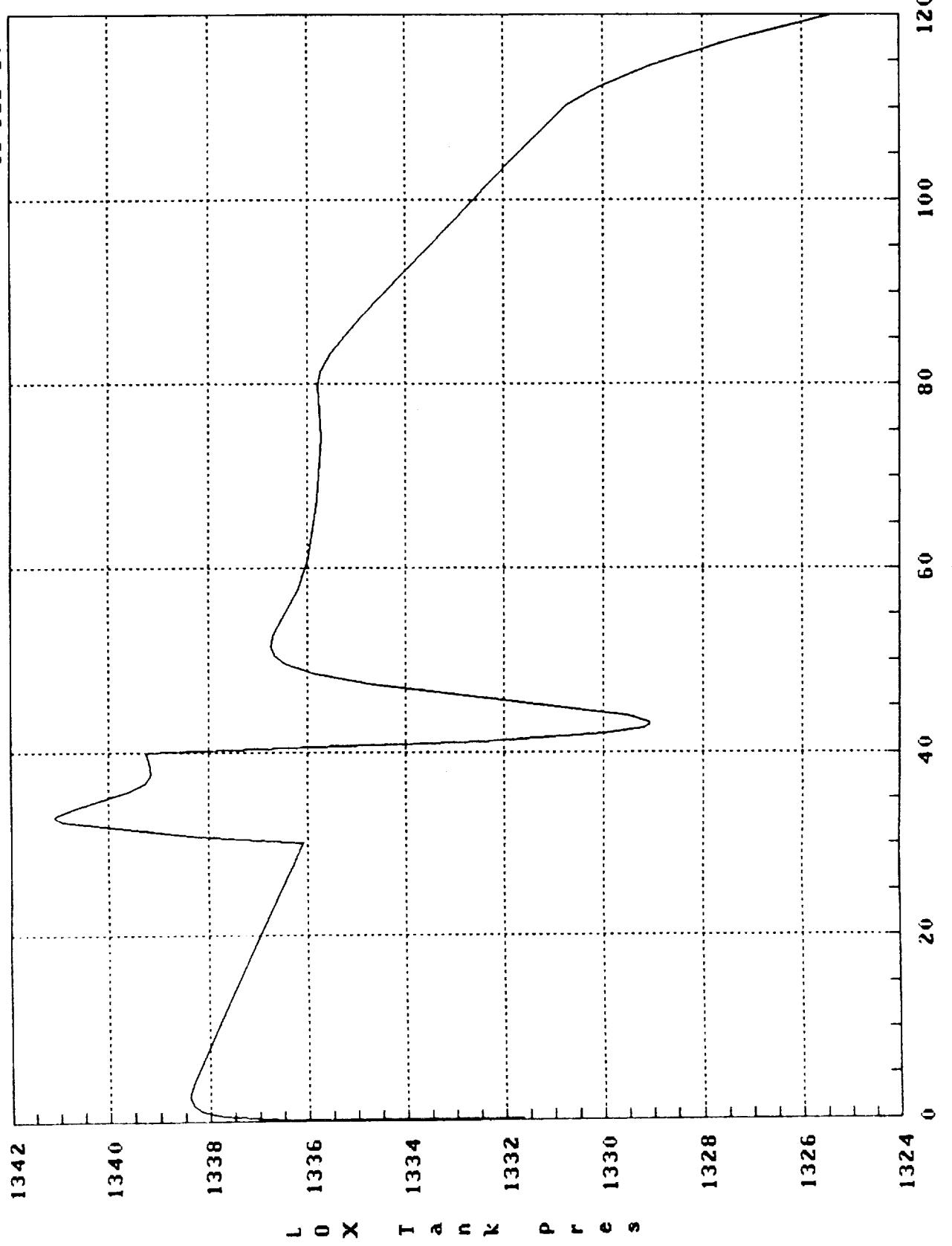
CONFIGURATION 42 FAILED HEATER AT 40 SECONDS



CONFIGURATION 42 FAILED HEATER AT 40 SECONDS

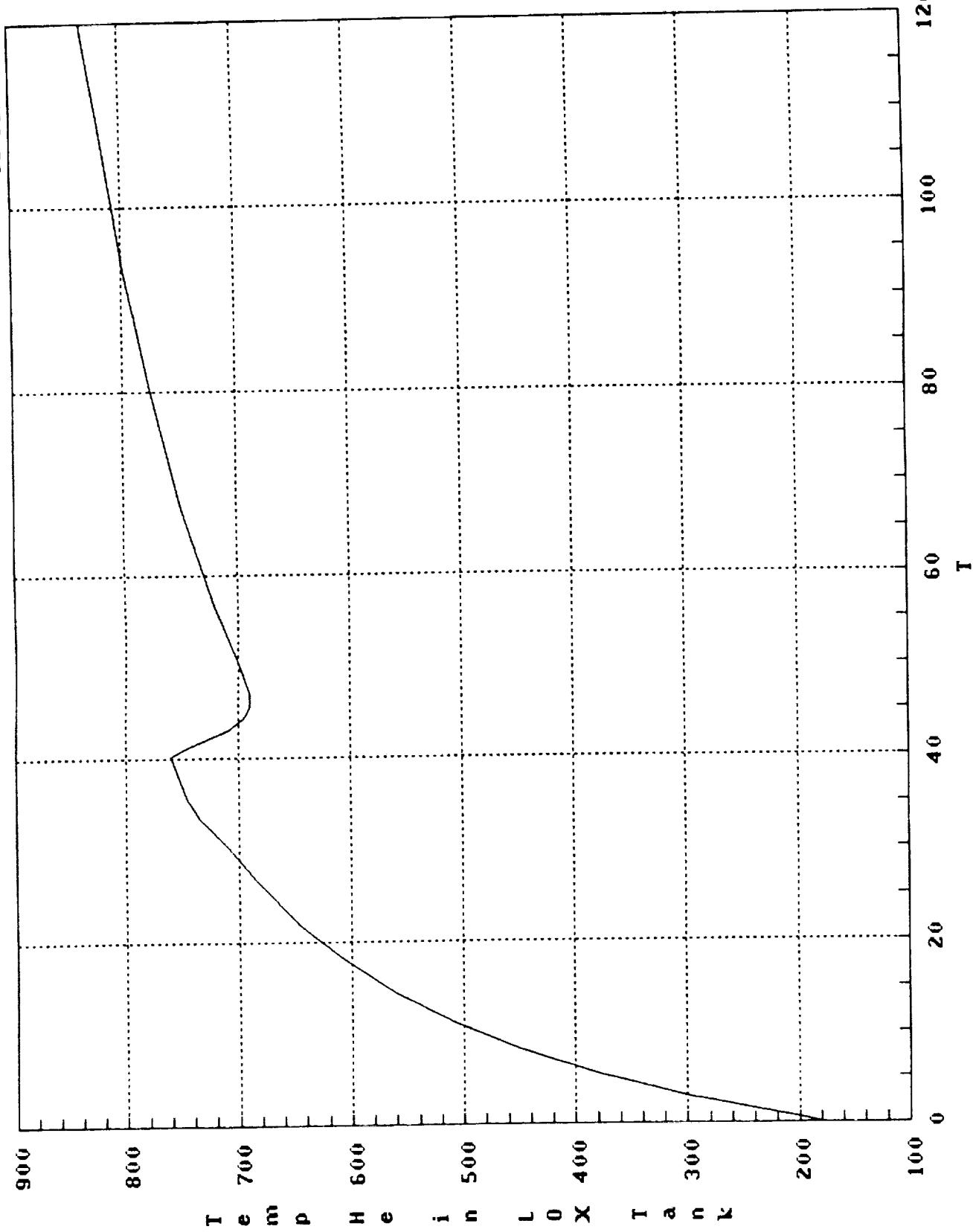


16-FEB-90



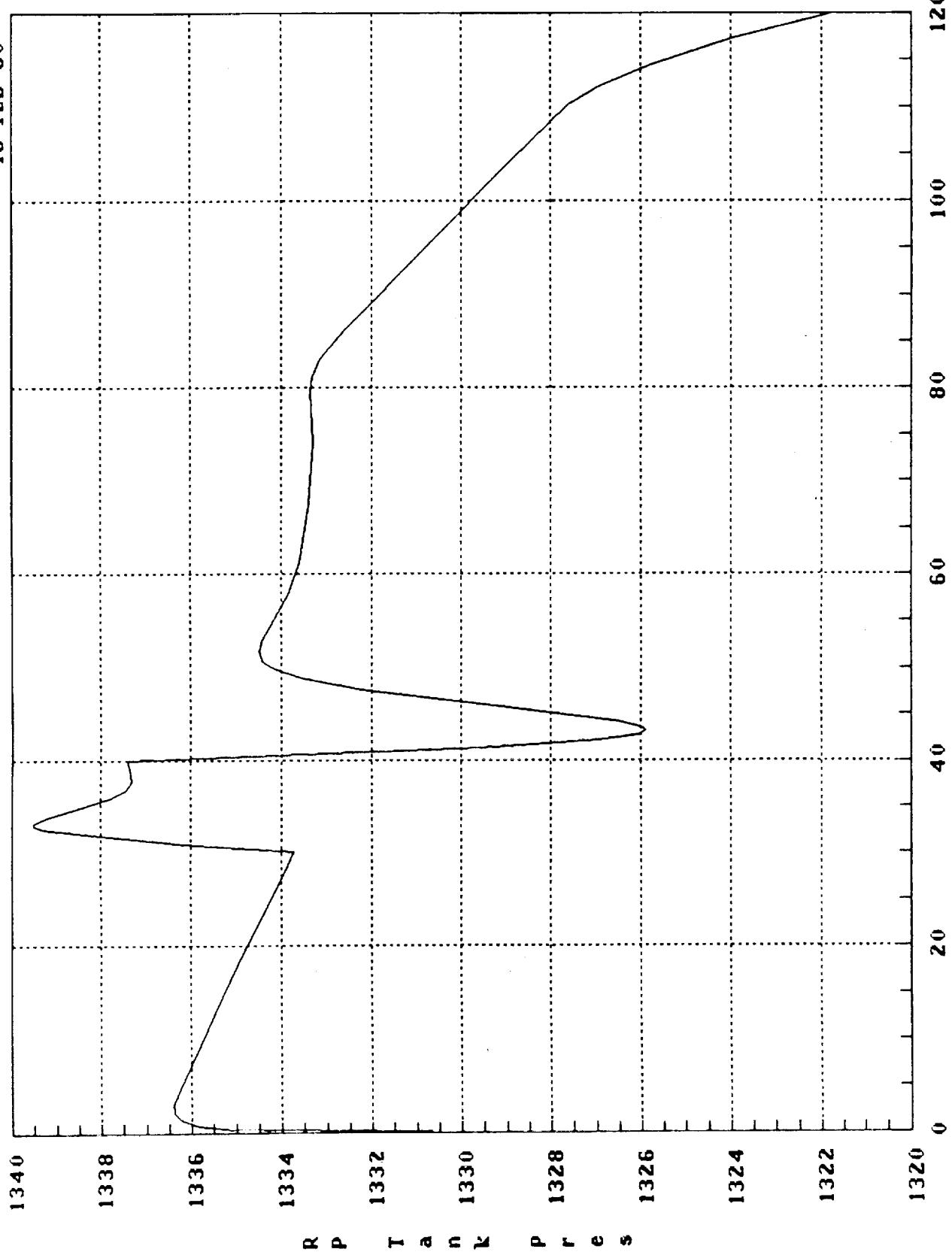
CONFIGURATION 42 FAILED HEATER AT 40 SECONDS

16-FEB-90



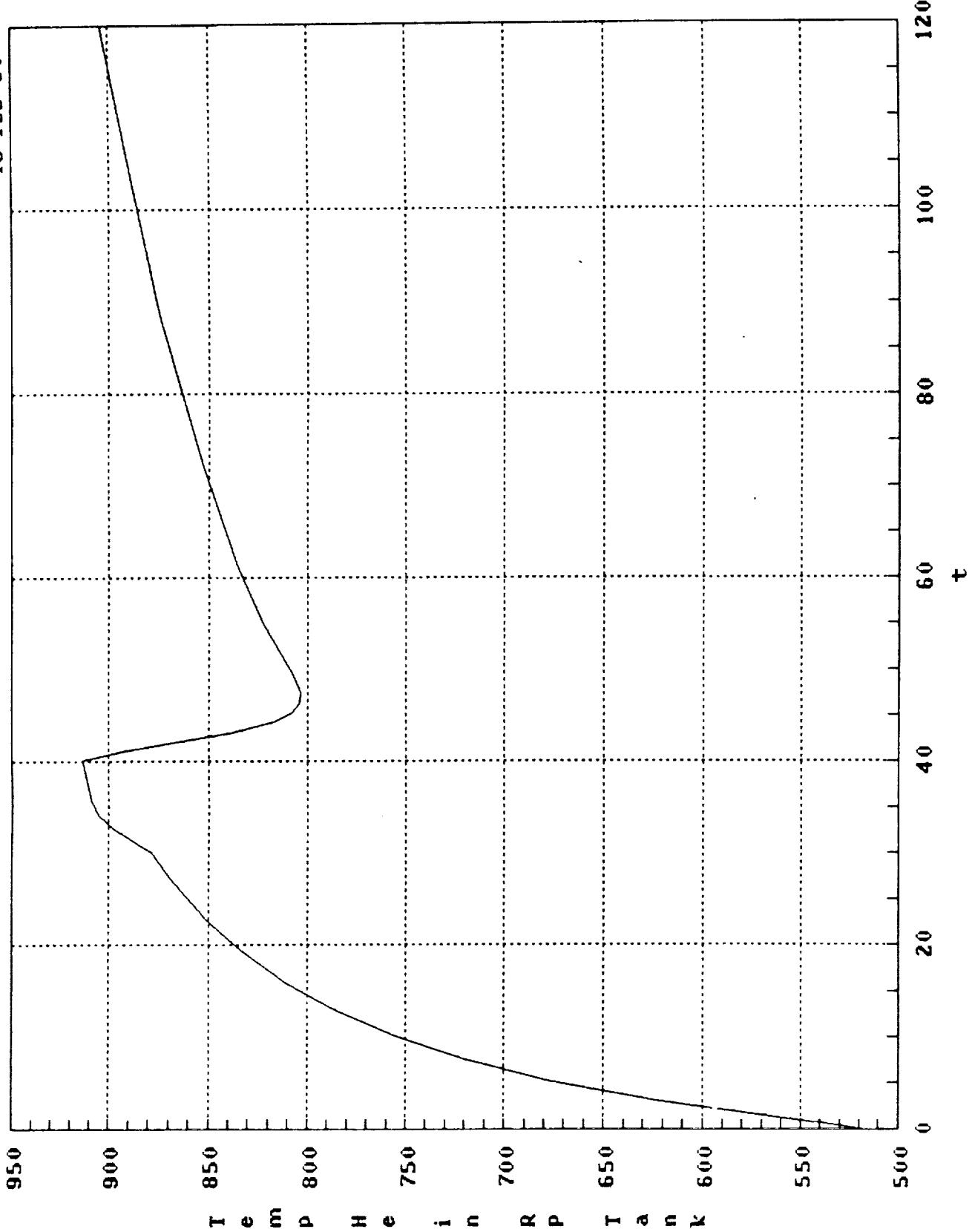
CONFIGURATION 42 FAILED HEATER AT 40 SECONDS

16-FEB-90



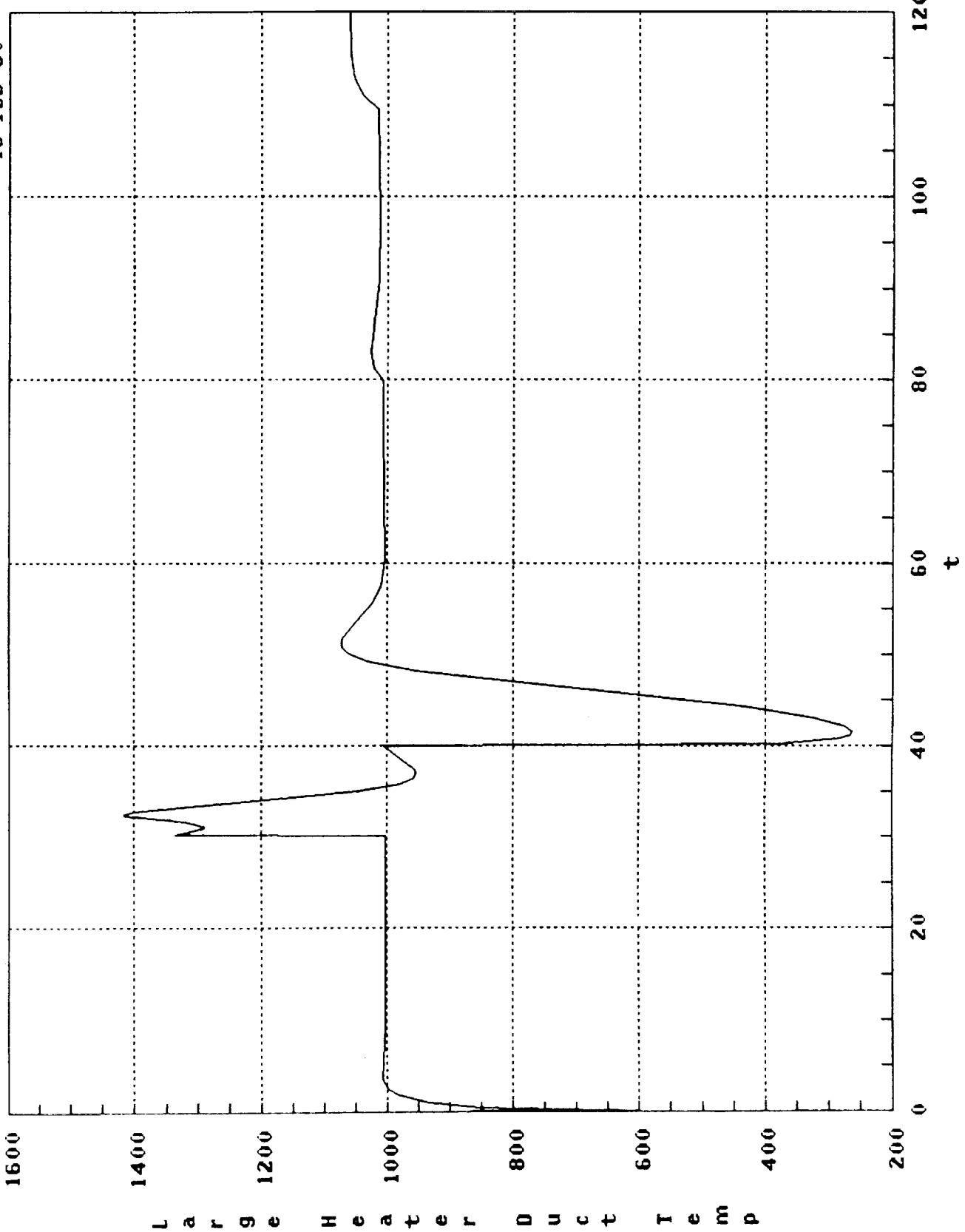
CONFIGURATION 4Z FAILED HEATER AT 40 SECONDS

16-FEB-90



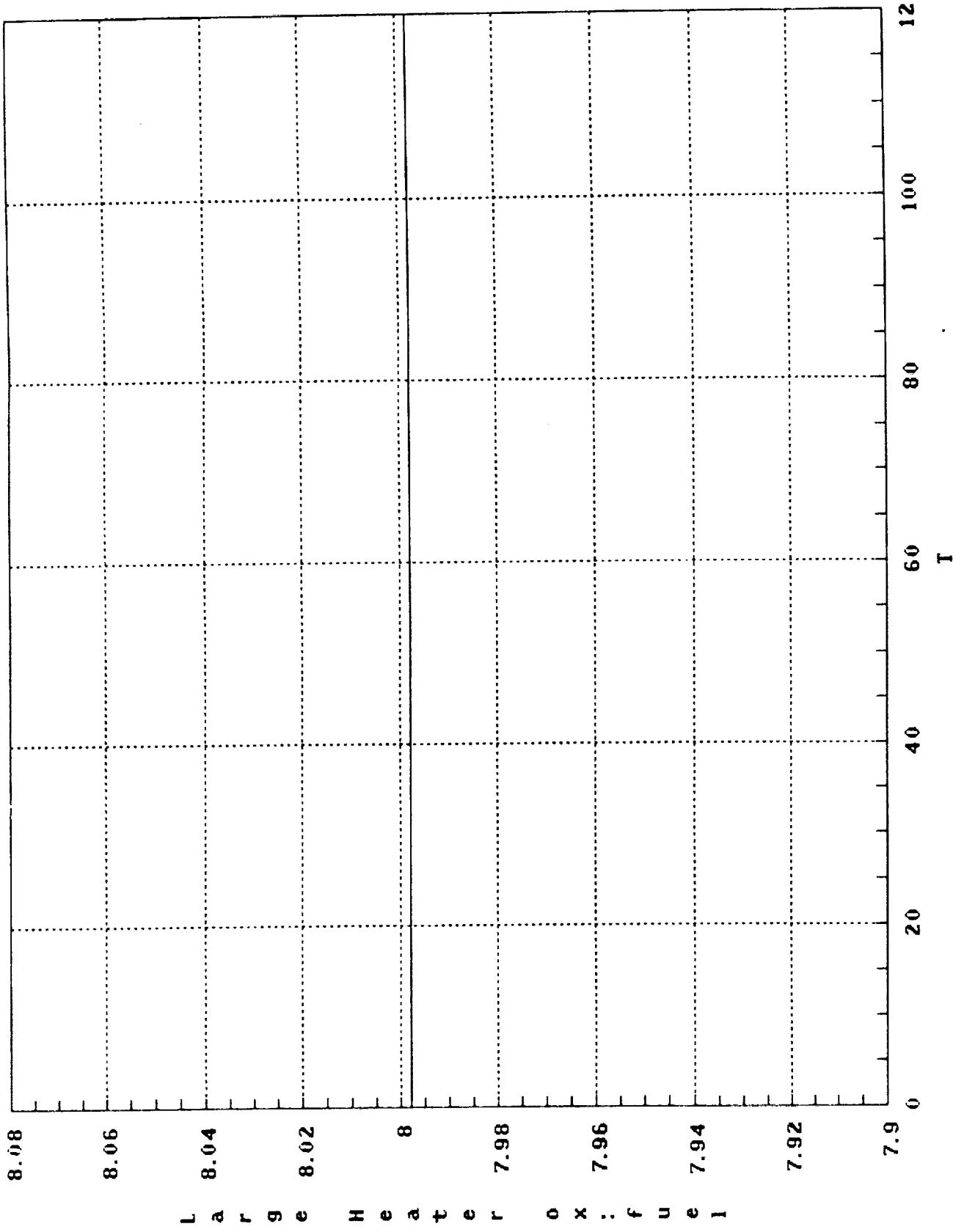
CONFIGURATION 42 FAILED HEATER AT 40 SECONDS

16-FEB-90



CONFIGURATION 42 FAILED HEATER AT 40 SECONDS

16-FEB-90

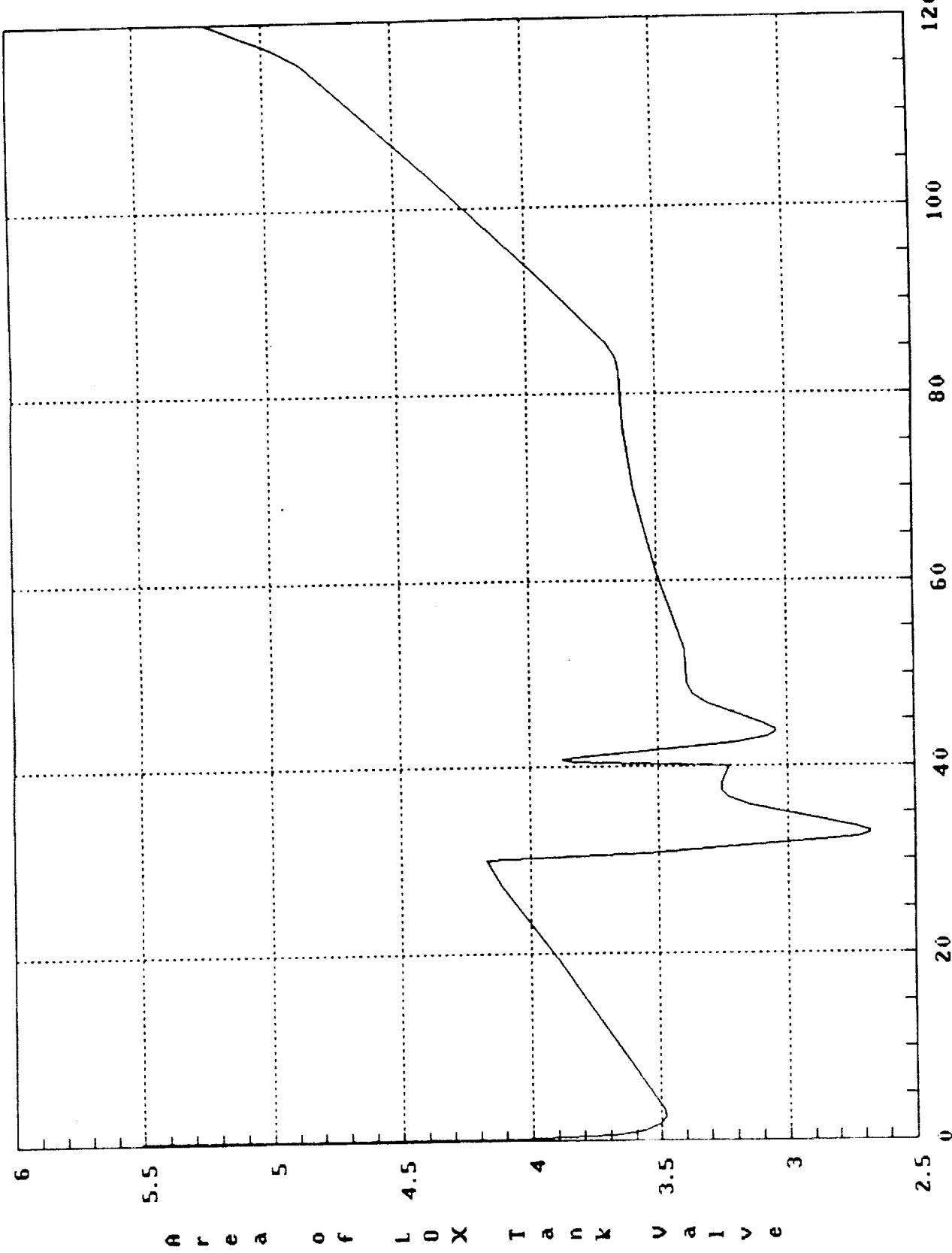


CONFIGURATION 42 FAILED HEATER AT 40 SECONDS

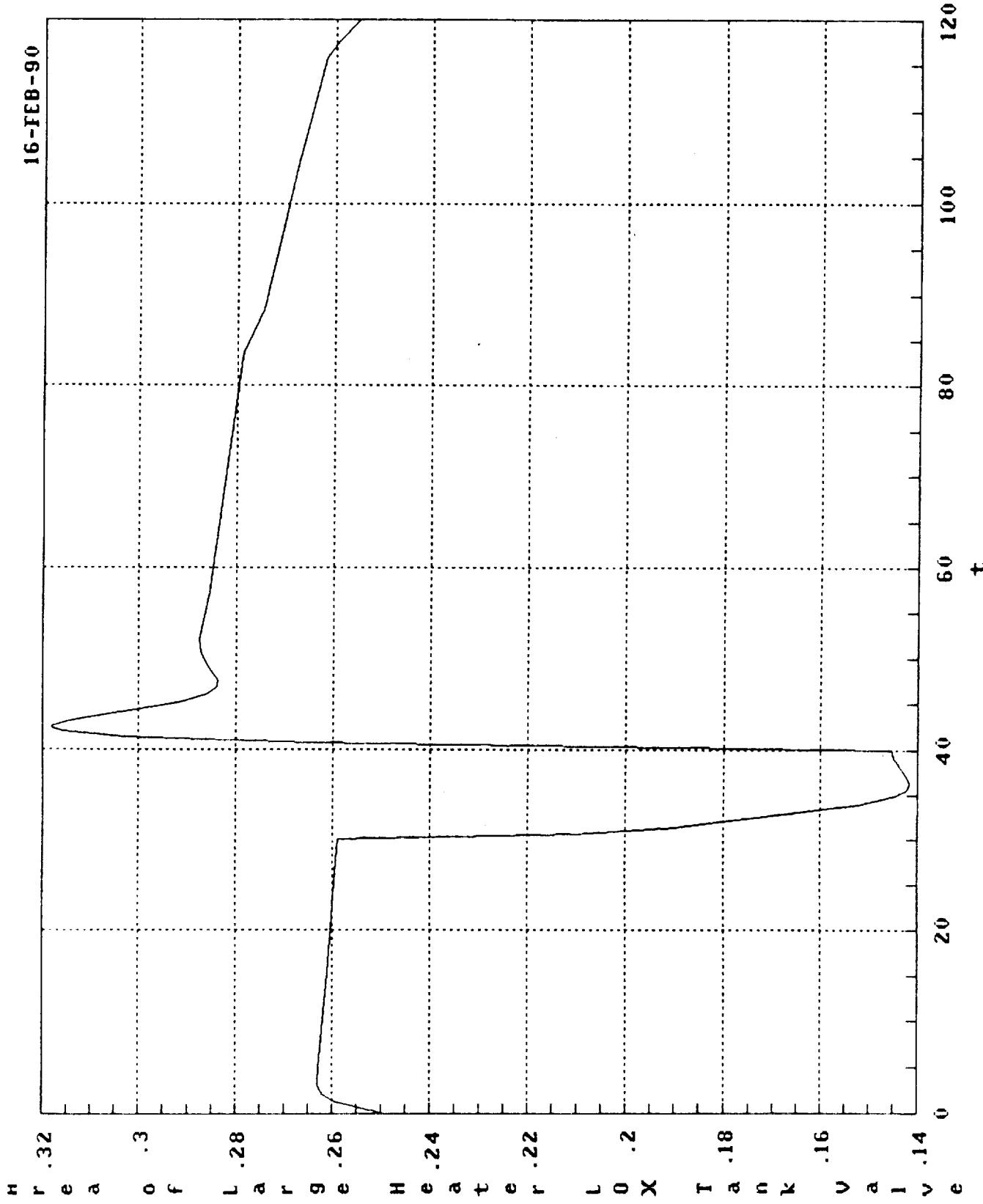
CONFIGURATION 4Z - - FAILURE MODES

- TOTAL HELIUM FLOW DIVIDED 50% PER PRIMARY HEATER PRIOR TO FAILURE
 - LOSS OF 1 PRIMARY HEATER AT $T = 40$ SEC
 - TOTAL HELIUM FLOW RATE THROUGH "GOOD" HEATER AFTER FAILURE
 - HEATER LOX/LH₂ VALVES SET AT 25% AT START-UP
 - HEATER LOX/LH₂ VALVES THROTTLED FROM 50% TO 100% TO ADJUST FOR INCREASED HELIUM FLOW AT FAILURE
 - PERCENTAGE OF TOTAL HELIUM FLOW THROUGH GOOD HEATER
- | | |
|------------------------------|-------|
| $T = 0 \rightarrow 30$ SEC | 50% |
| $T = 30 \rightarrow 40$ SEC | 37.5% |
| $T = 40 \rightarrow 120$ SEC | 75% |

16-FEB-96

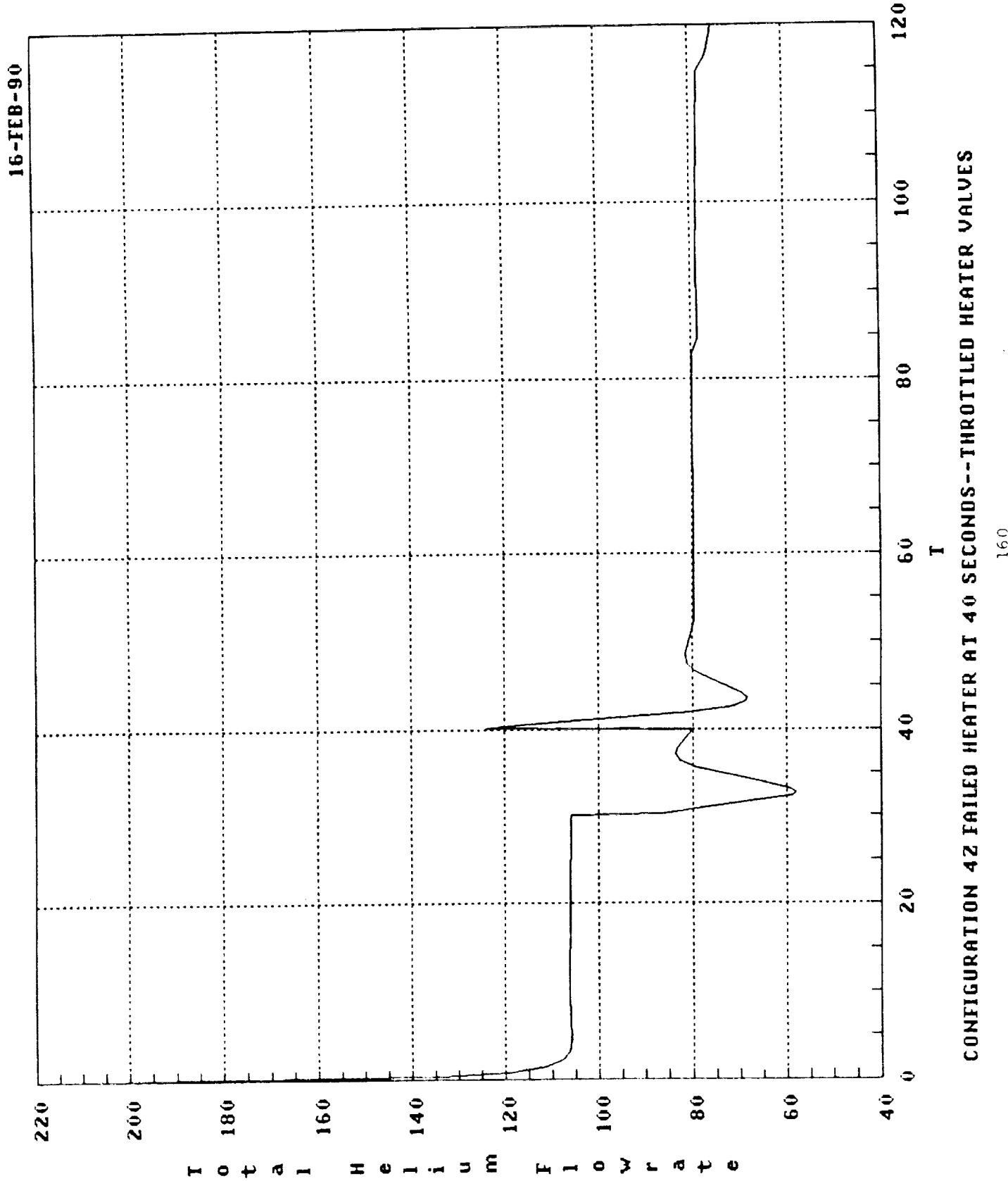


CONFIGURATION 42 FAILED HEATER AT 40 SECONDS--THROTTLED HEATER VALUES



CONFIGURATION 42 FAILED HEATER AT 40 SECONDS--THROTTLED HEATER VALUES

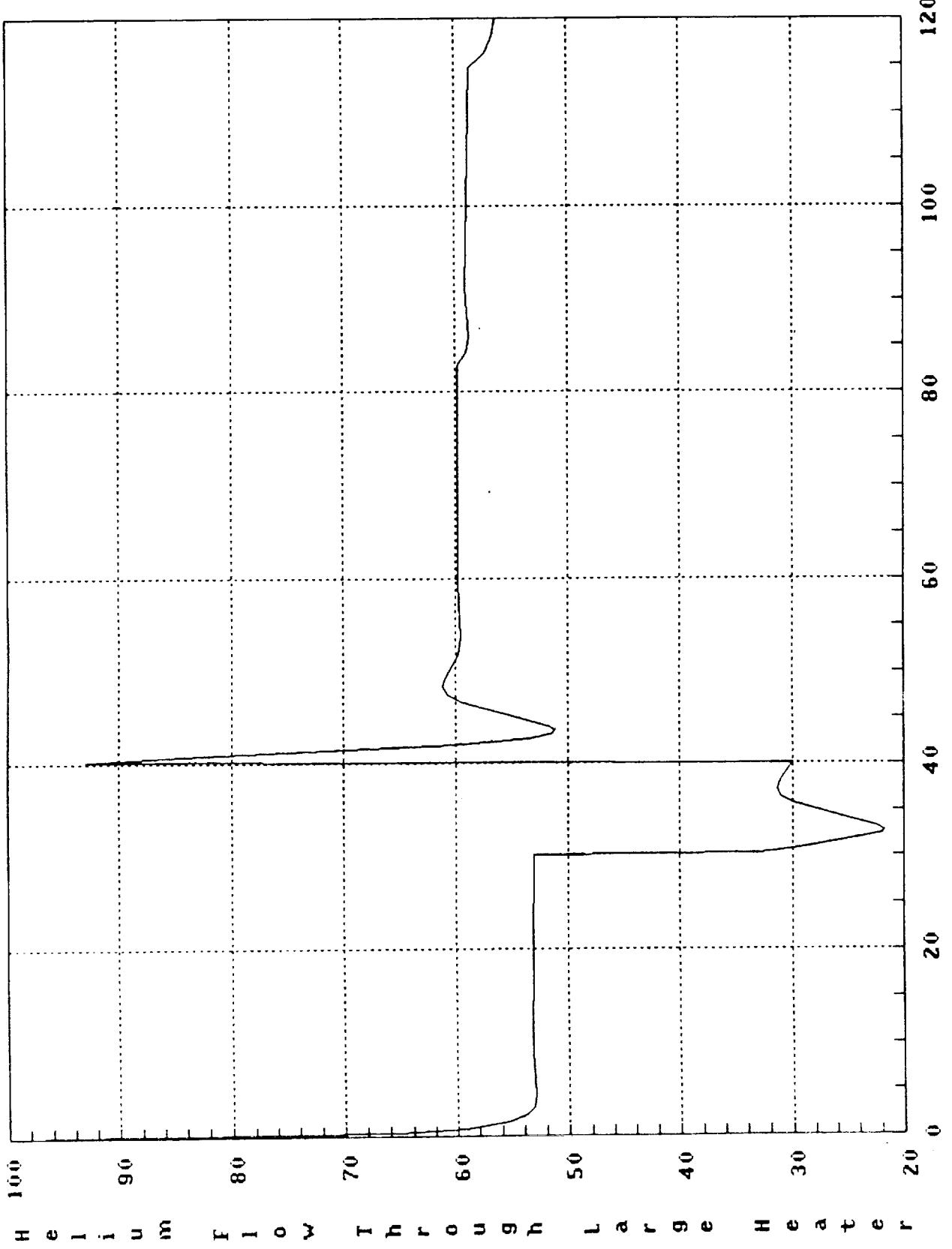
16-FEB-90



CONFIGURATION 42 FAILED HEATER AT 40 SECONDS--THROTTLED HEATER VALUES

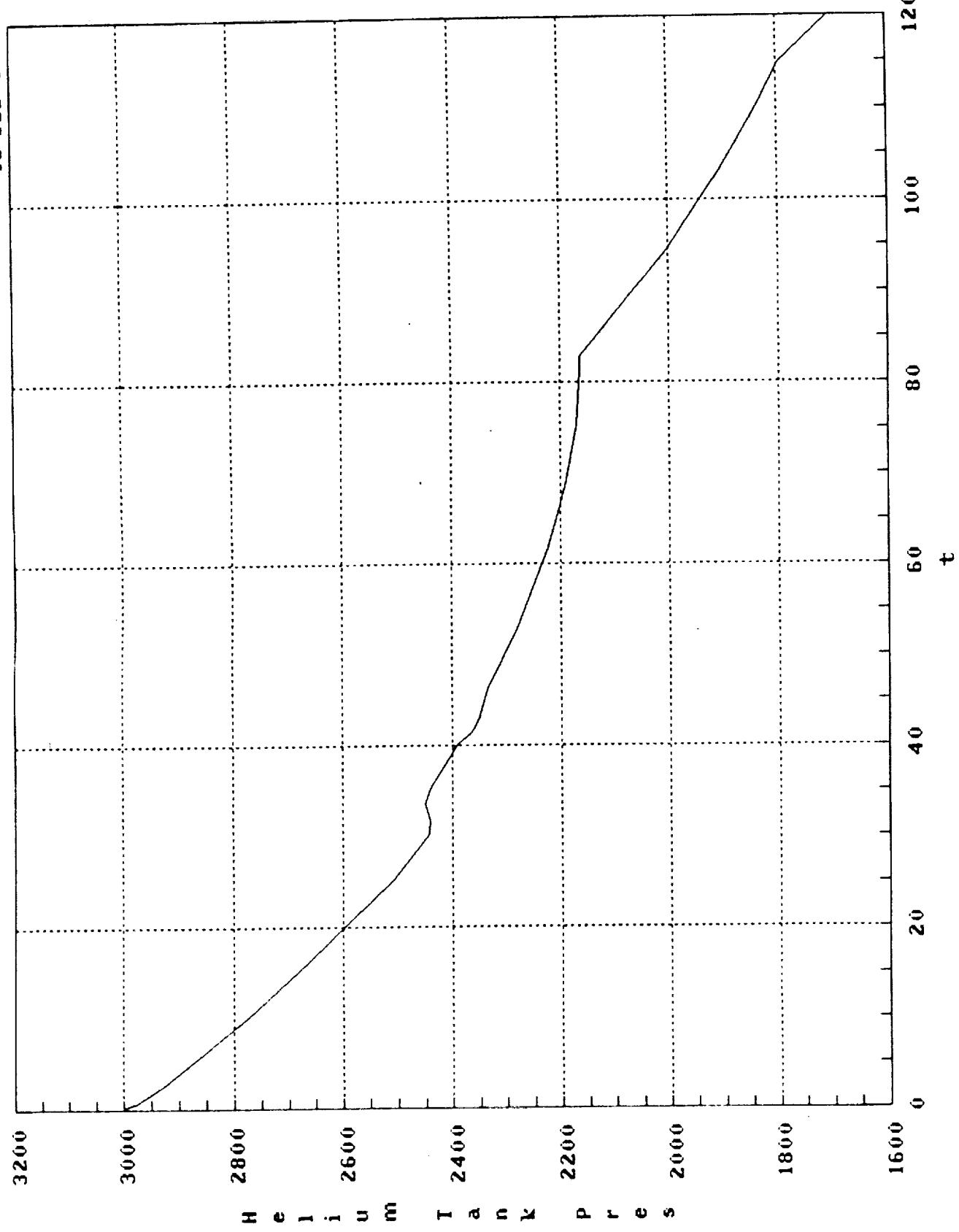
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16-FEB-90

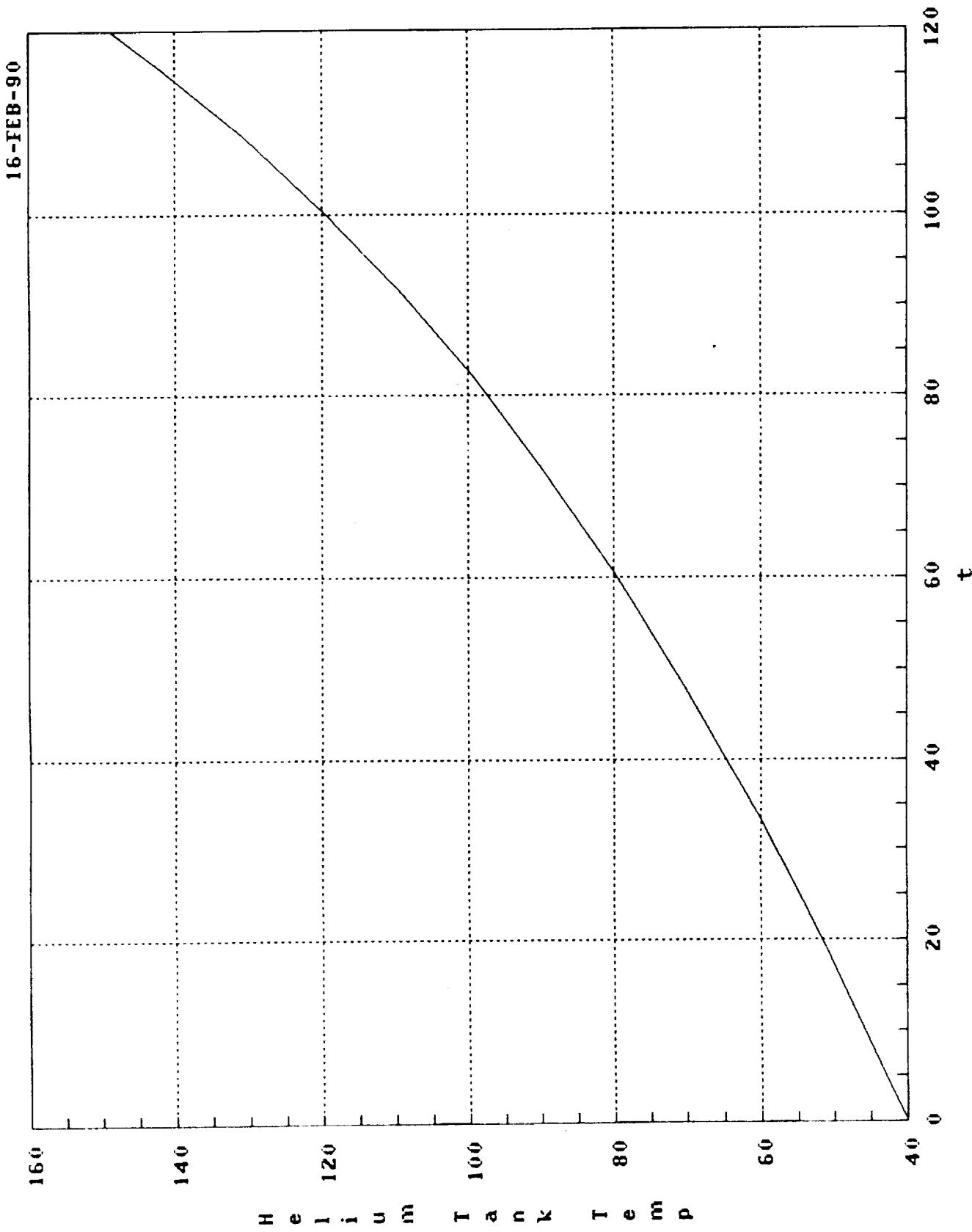


CONFIGURATION 42 FAILED HEATER AT 40 SECONDS--THROTTLED HEATER VALVES

16-FEB-90

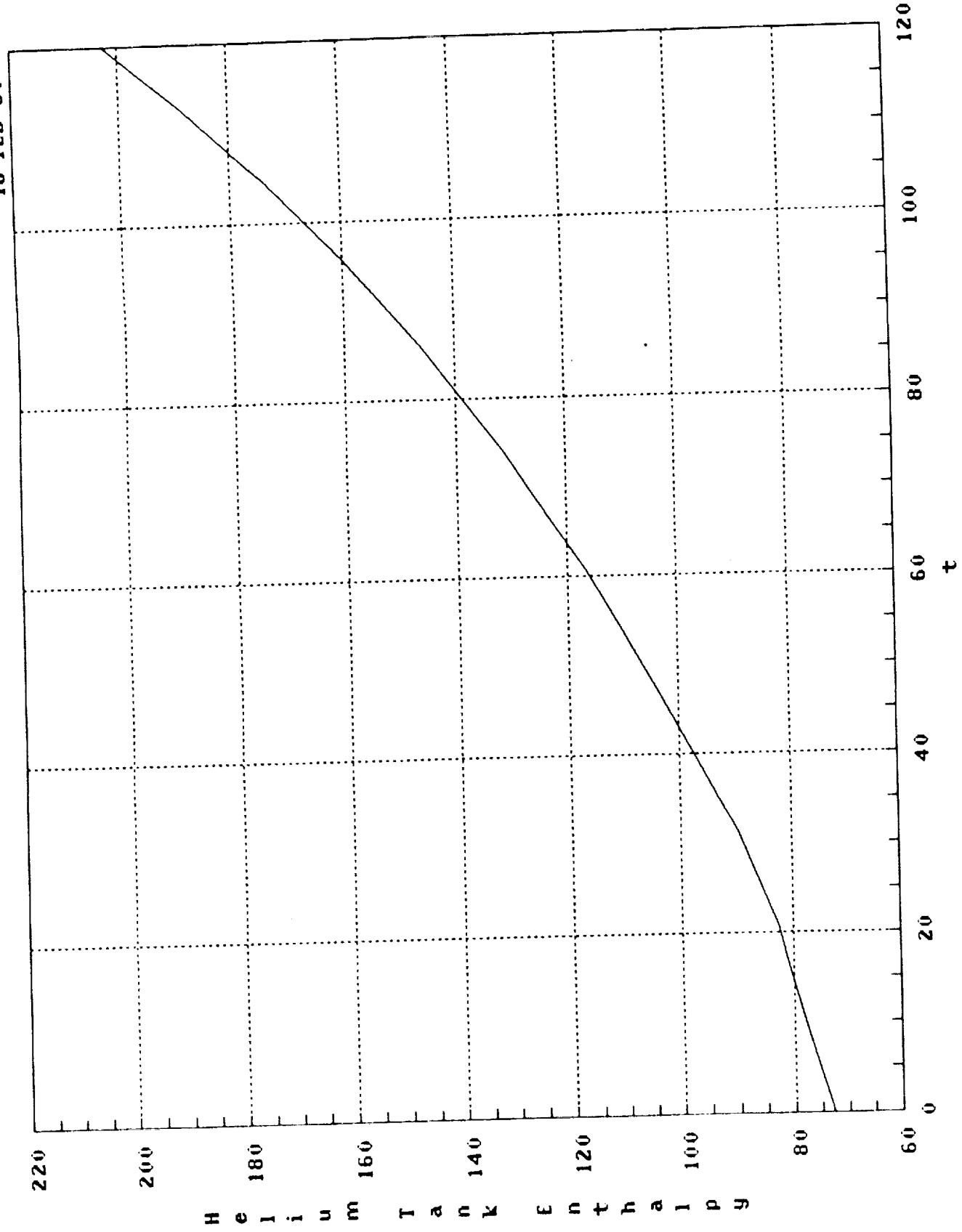


CONFIGURATION 42 FAILED HEATER AT 40 SECONDS--THROTTLED HEATER VALUES



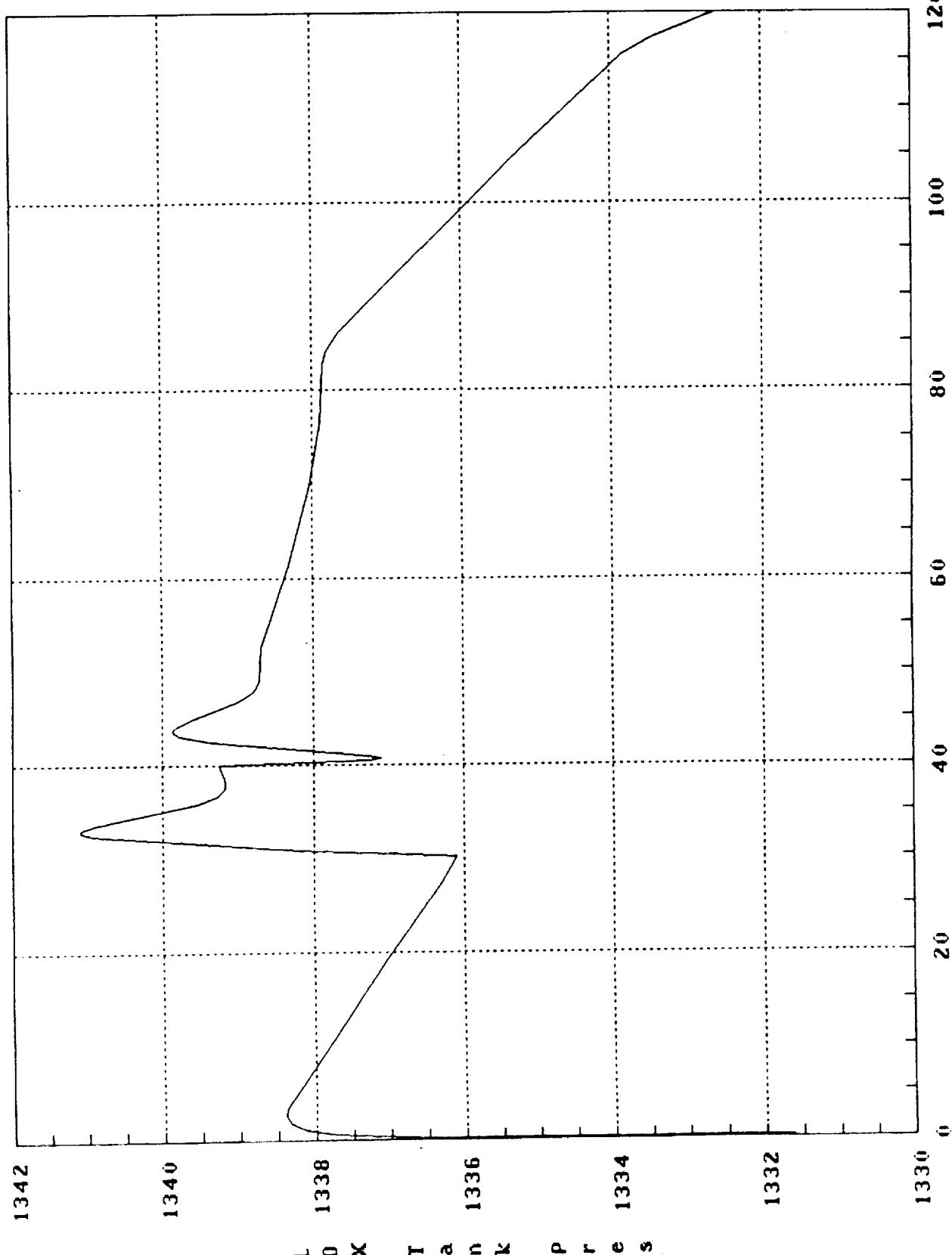
CONFIGURATION 42 FAILED HEATER AT 40 SECONDS--THROTTLED HEATER VALUES

16-FEB-90

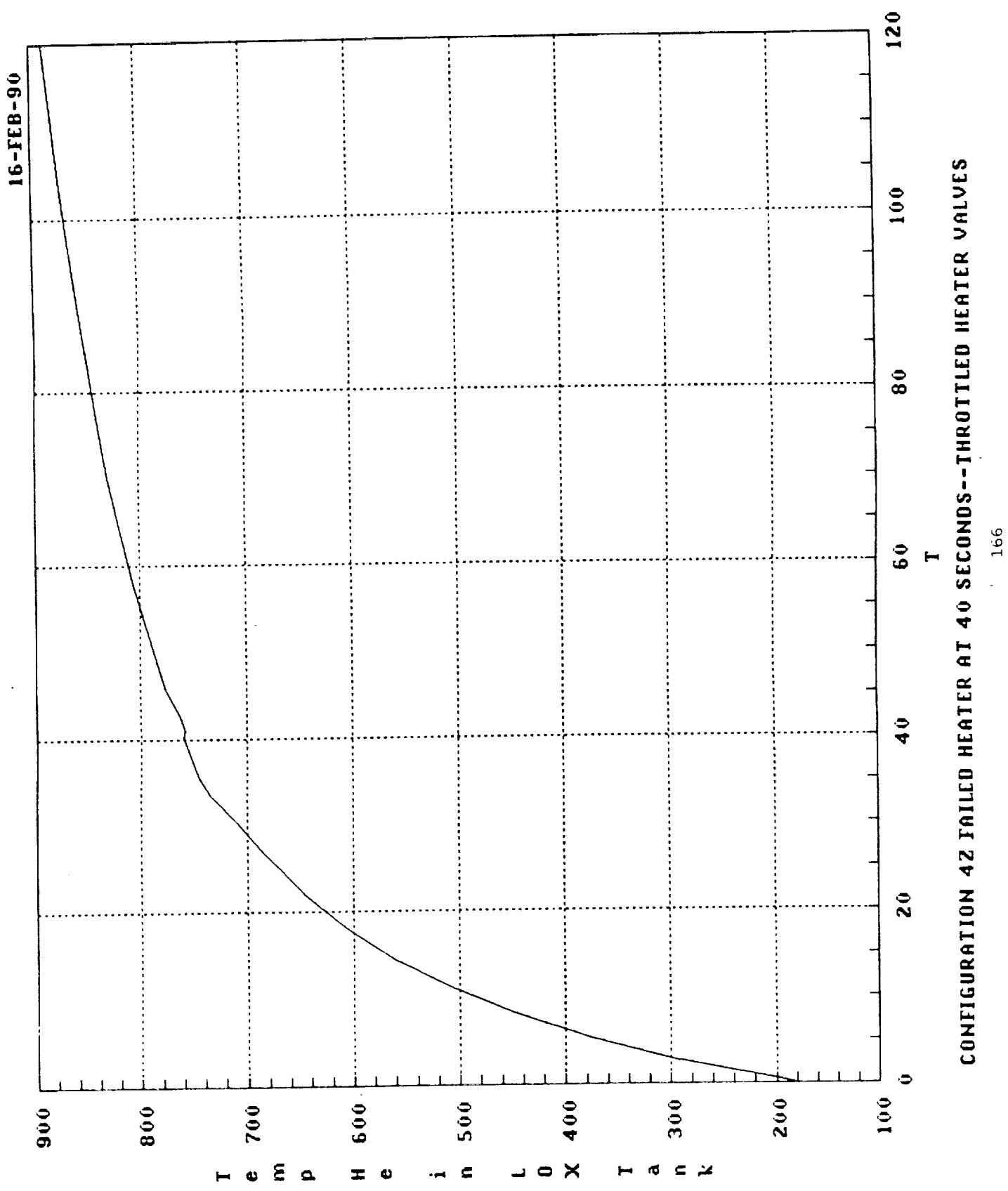


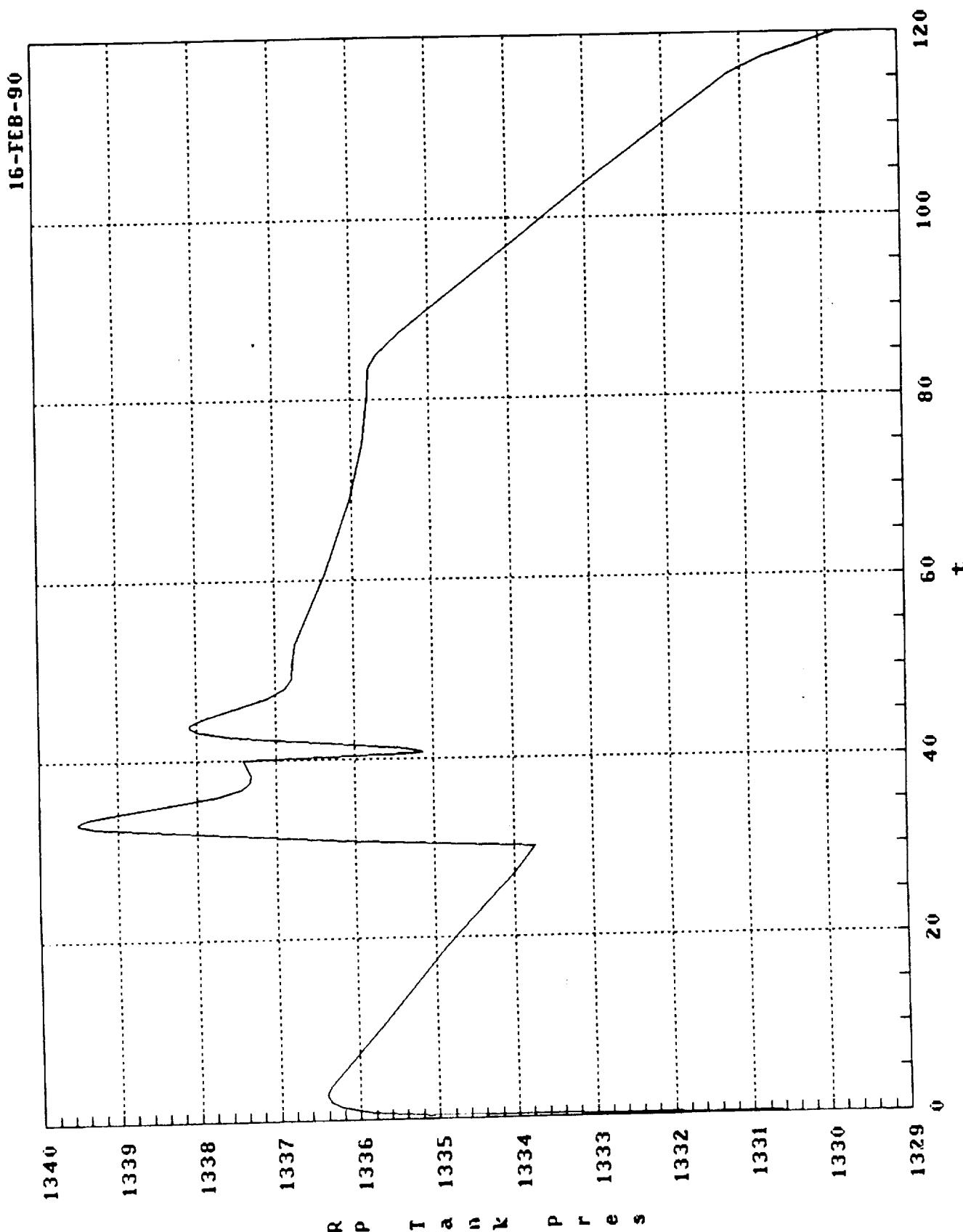
CONFIGURATION 42 FAILED HEATER AT 40 SECONDS--THROTTLED HEATER VALVES

16-FEB-90



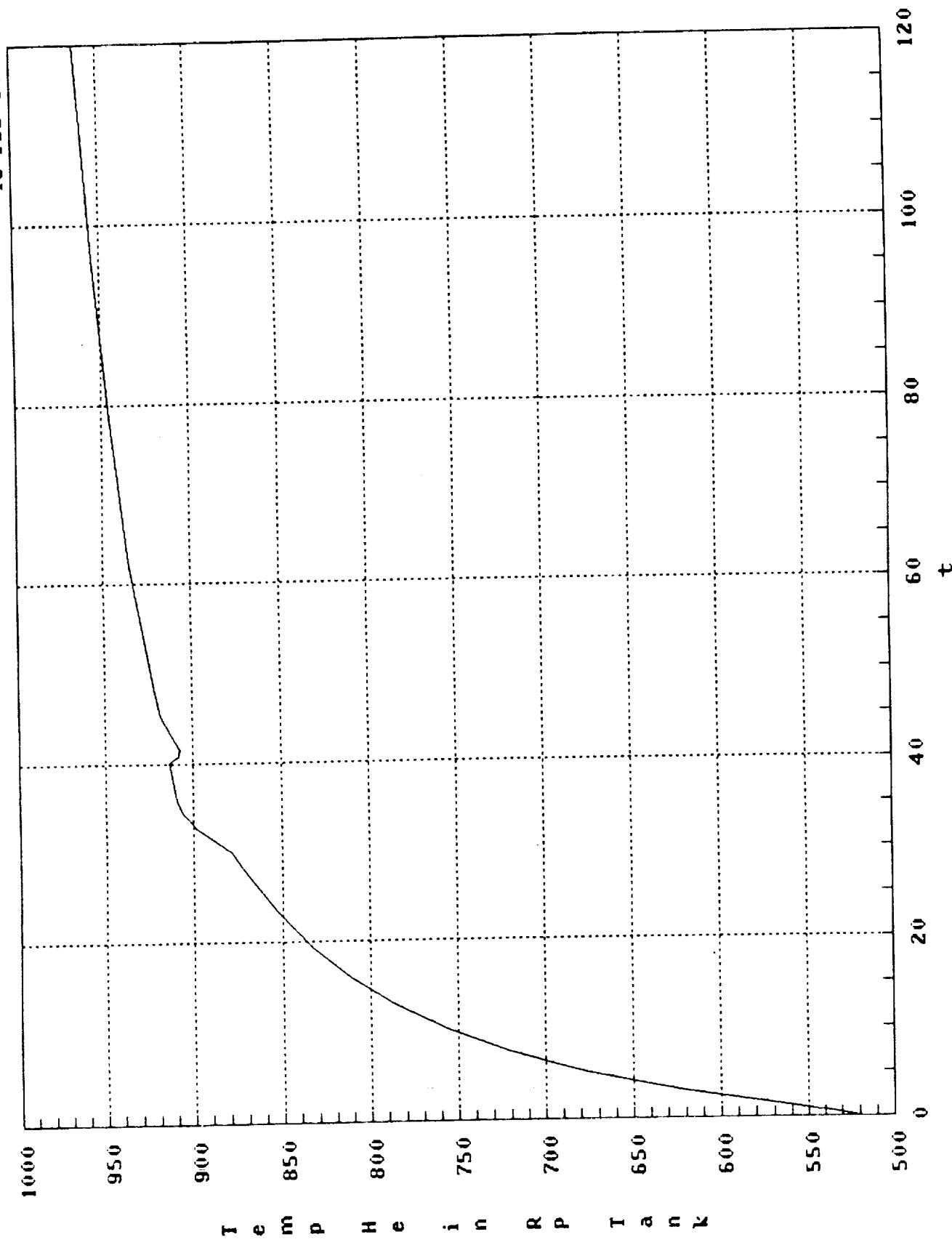
CONFIGURATION 42 FAILED HEATER AT 40 SECONDS--THROTTLED HEATER VALUES



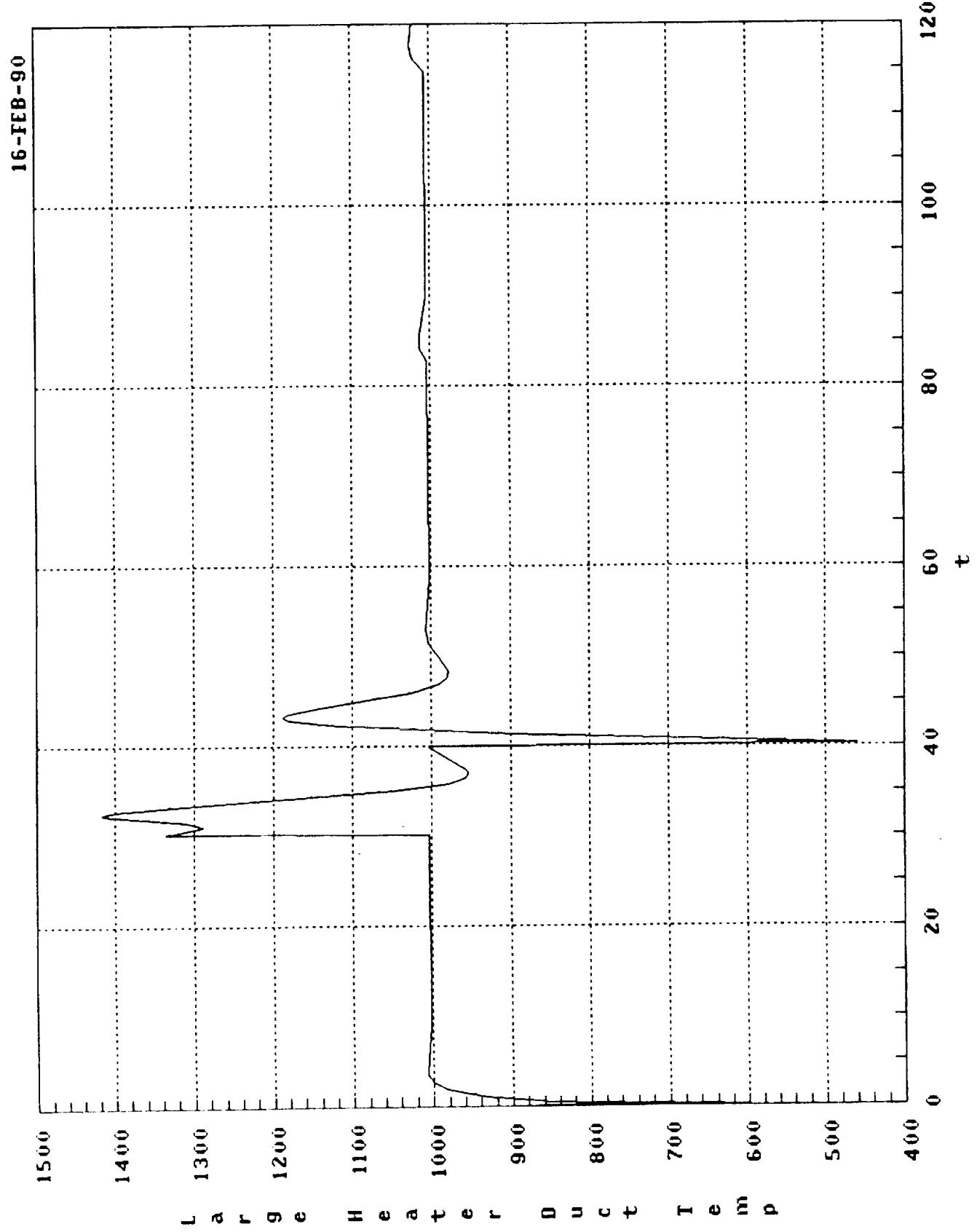


CONFIGURATION 42 FAILED HEATER AT 40 SECONDS--THROTTLED HEATER VALVES

16-FEB-90



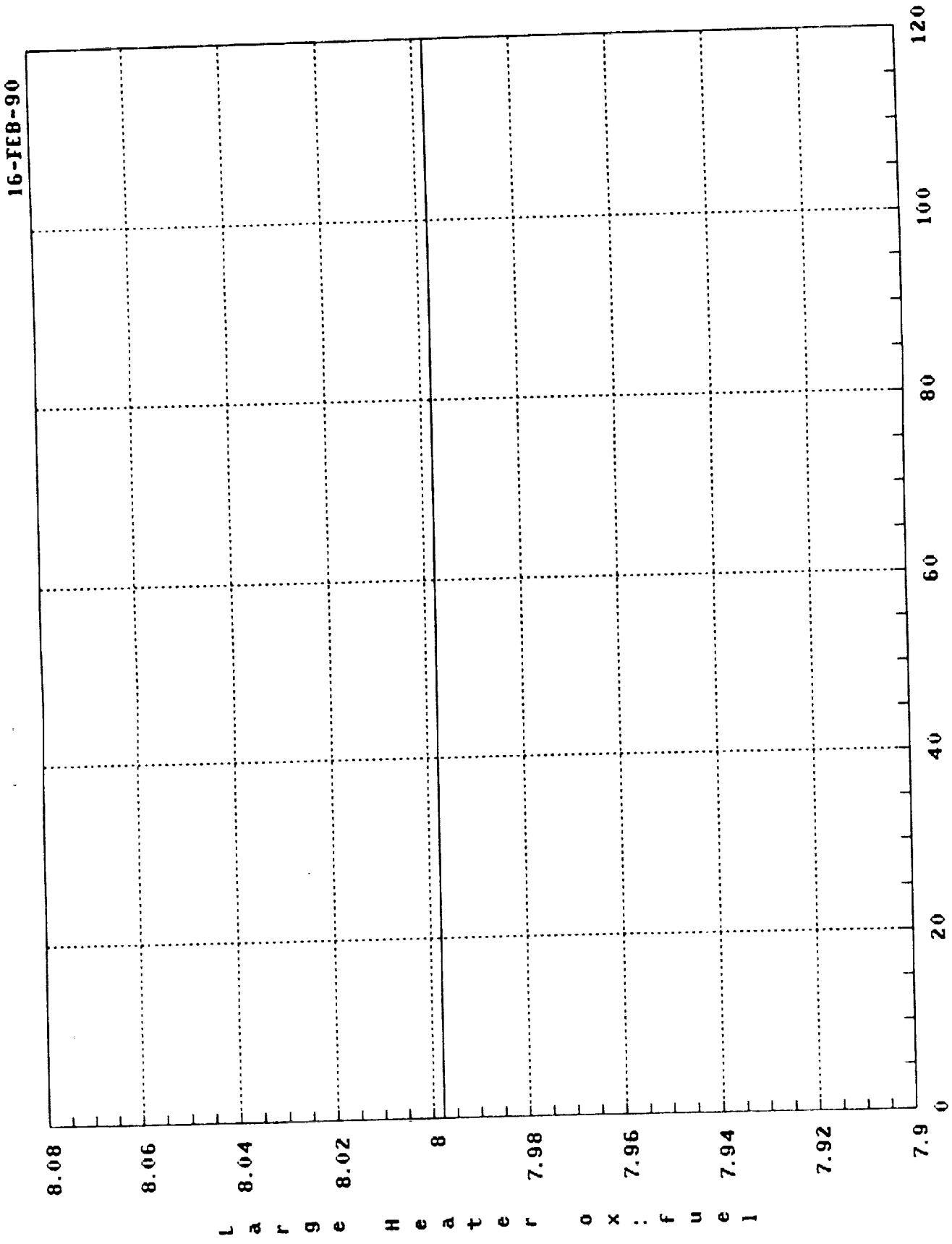
CONFIGURATION 4Z FAILED HEATER AT 40 SECONDS-- THROTTLED HEATER VALUES



CONFIGURATION 42 FAILED HEATER AT 40 SECONDS--THROTTLED HEATER VALVES

CONFIGURATION 42 TAILED HEATER AT 40 SECONDS--THROTTLED HEATER VALUES

170



CONFIGURATION 2

GAS GENERATOR / HEAT EXCHANGER / STEAM

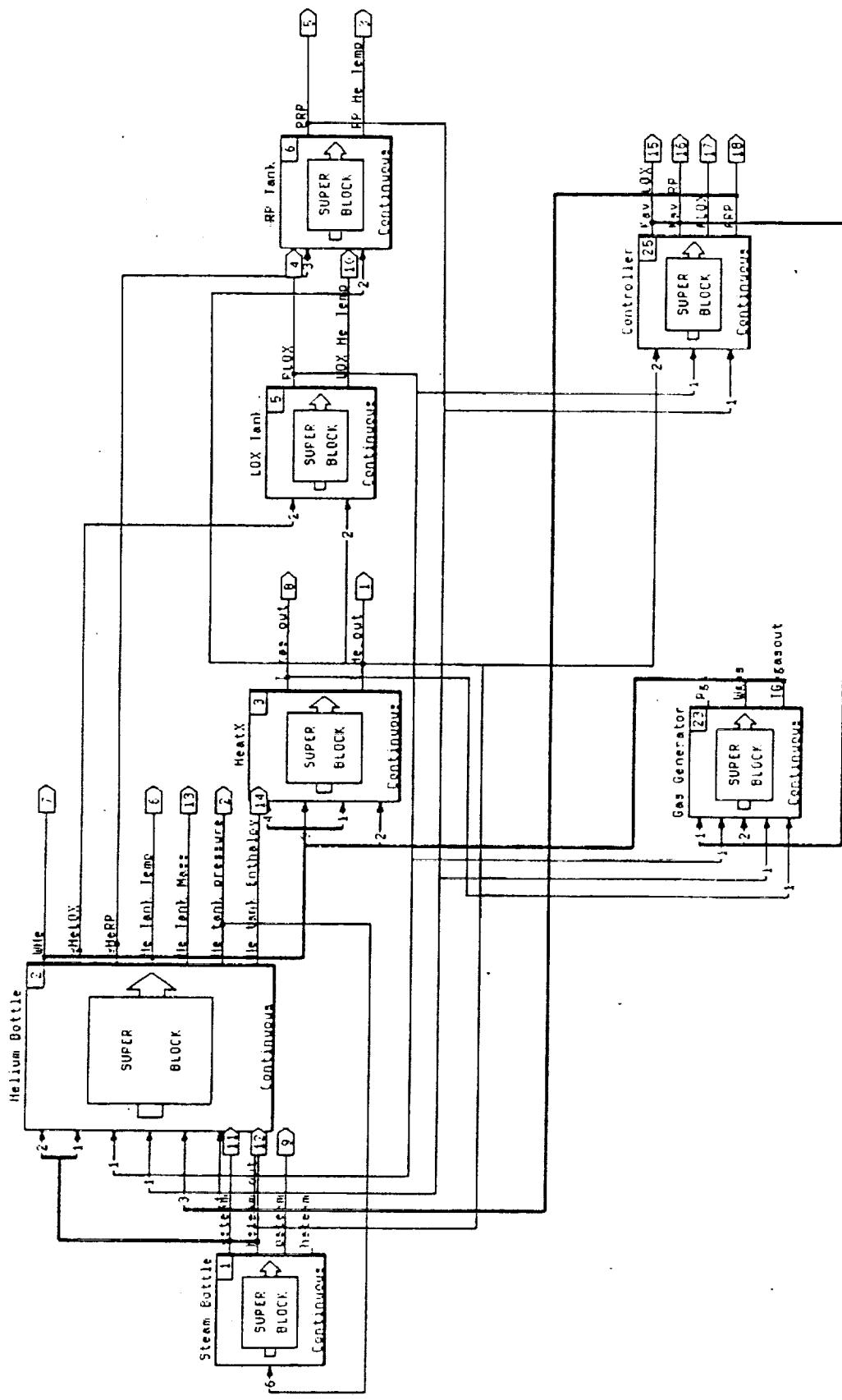
MATRIX X BLOCK DIAGRAMS

MATRIX X PLOTS

Honeywell

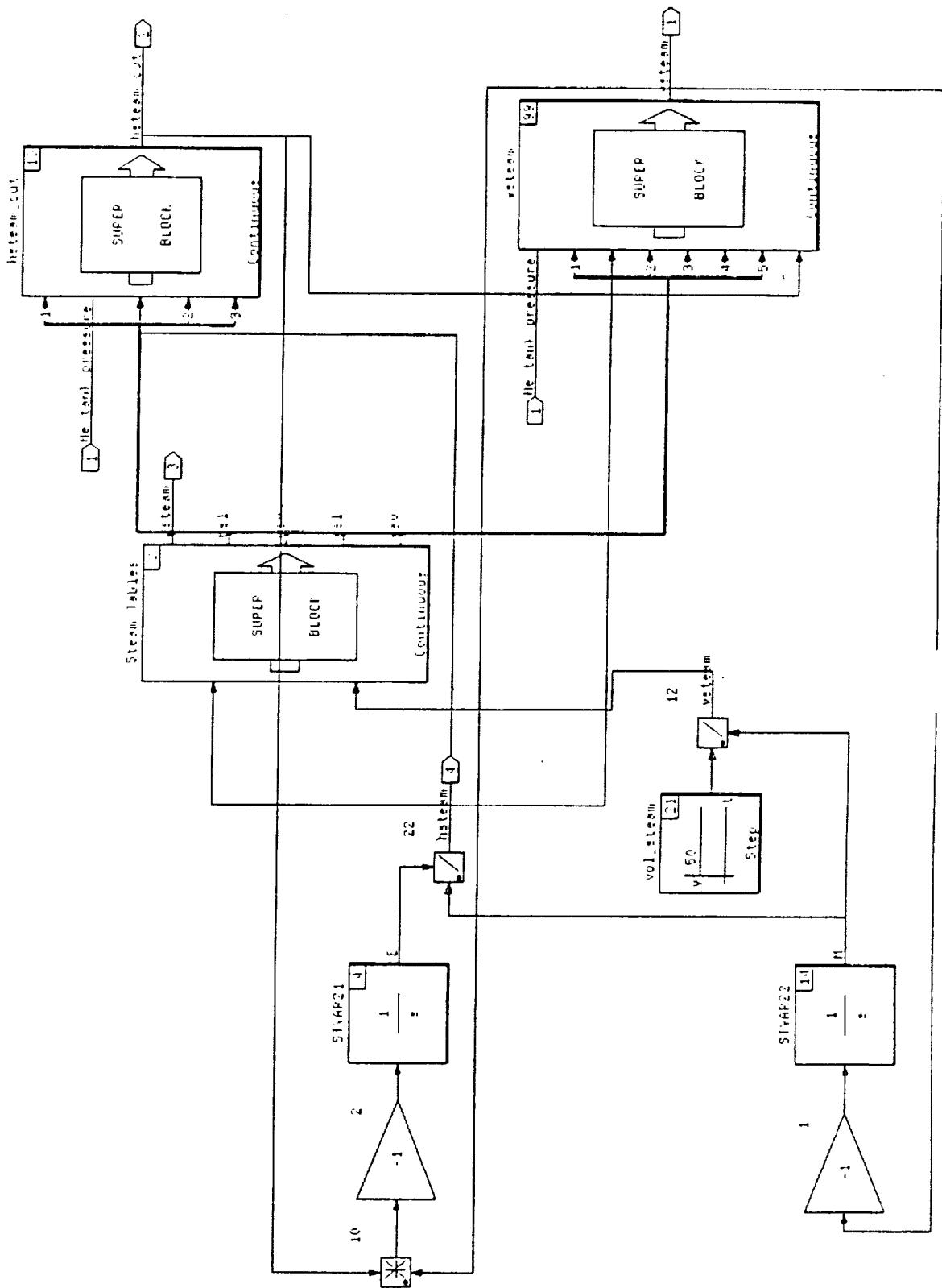
HINTS

Continuous Super-Block
Configuration 2 Ext. Inputs Ext. Outputs
0 18



HINTS

Continuous Super-Block:
Stream Bottles Ext. Inputs Ext. Outputs
1 4



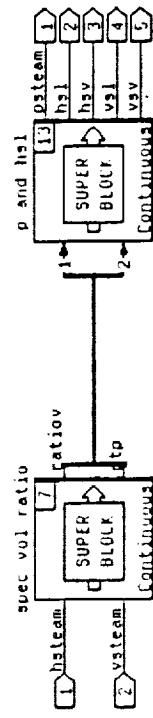
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Continuous Super-Block
Stream Tables

Ext. Inputs Ext. Outputs

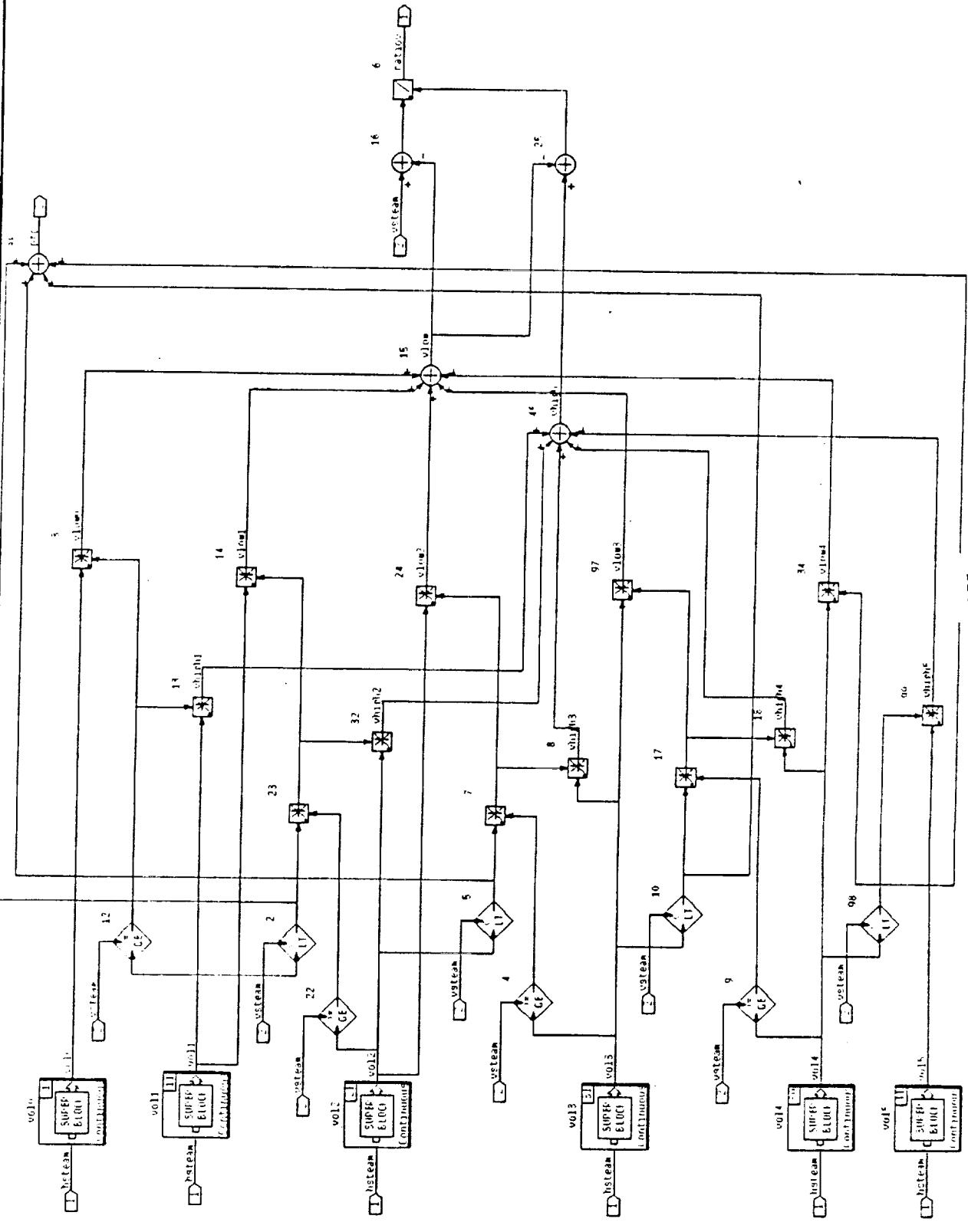
2

5



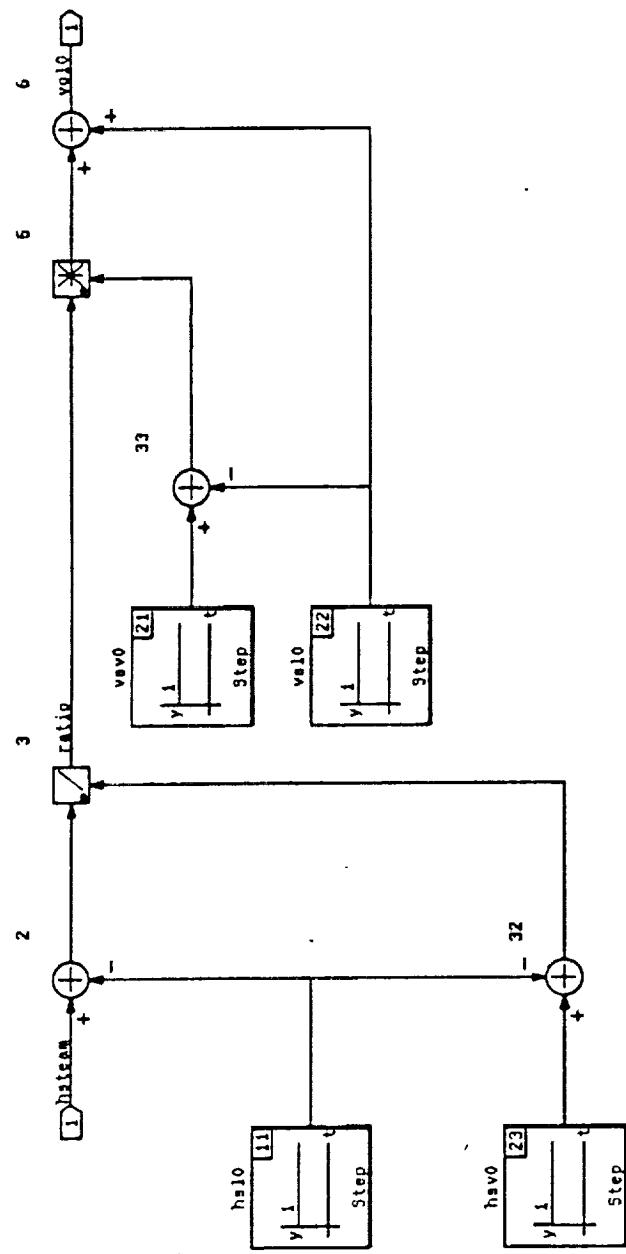
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Continuous Super-Block
Spec. vol ratio 2 Ext. Inputs Ext. Outputs 2



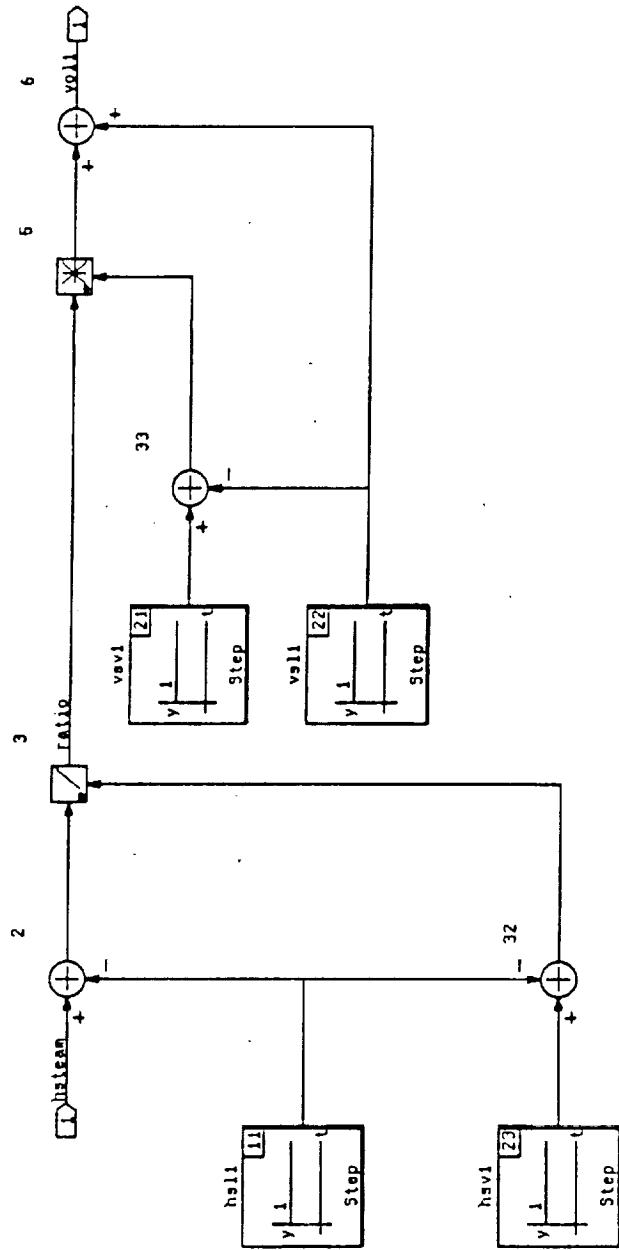
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Continuous Super-Block Ext. Inputs Ext. Outputs
v₀₁₀ 1 1



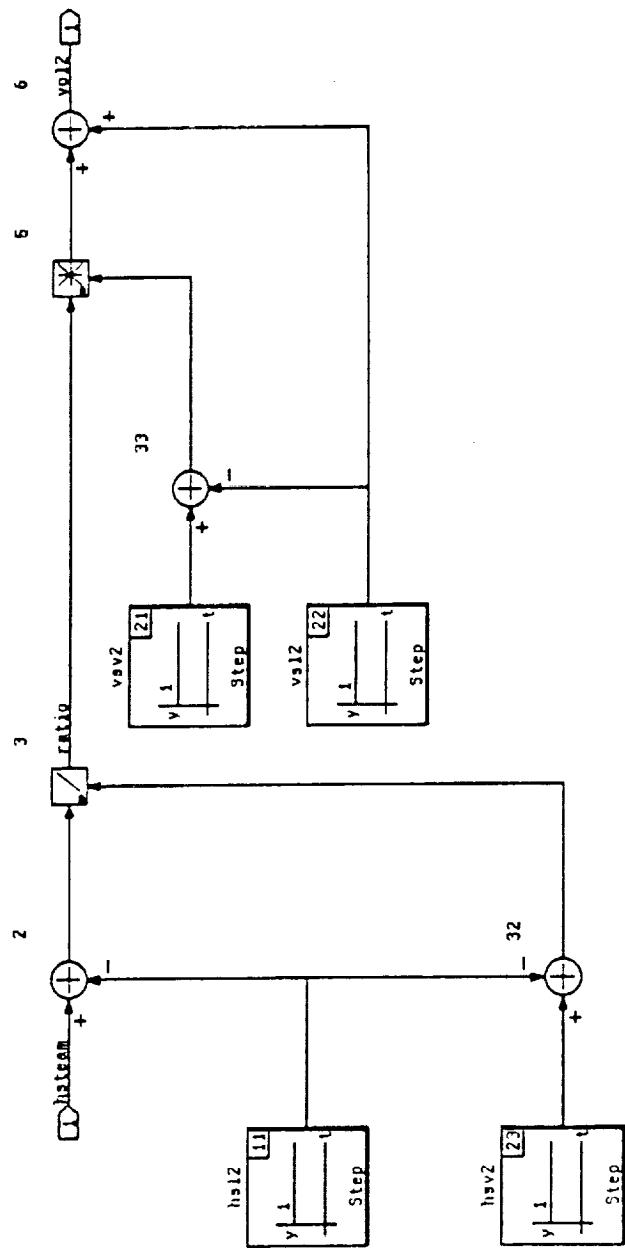
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
vol1 1 1



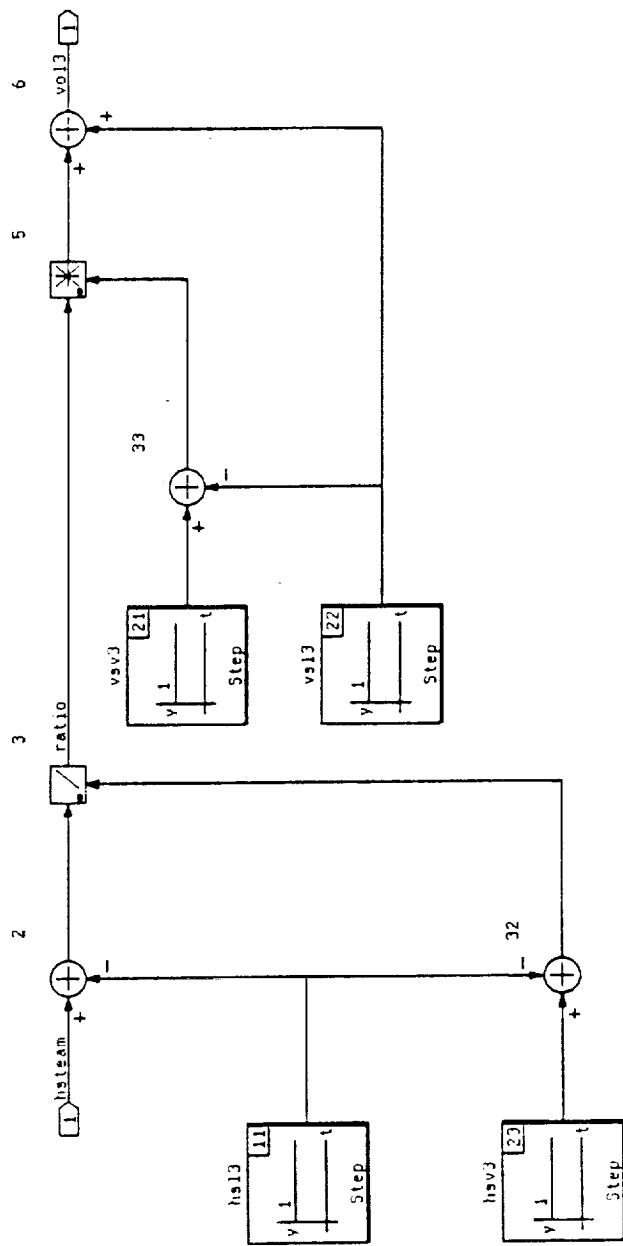
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
vol2 1 1



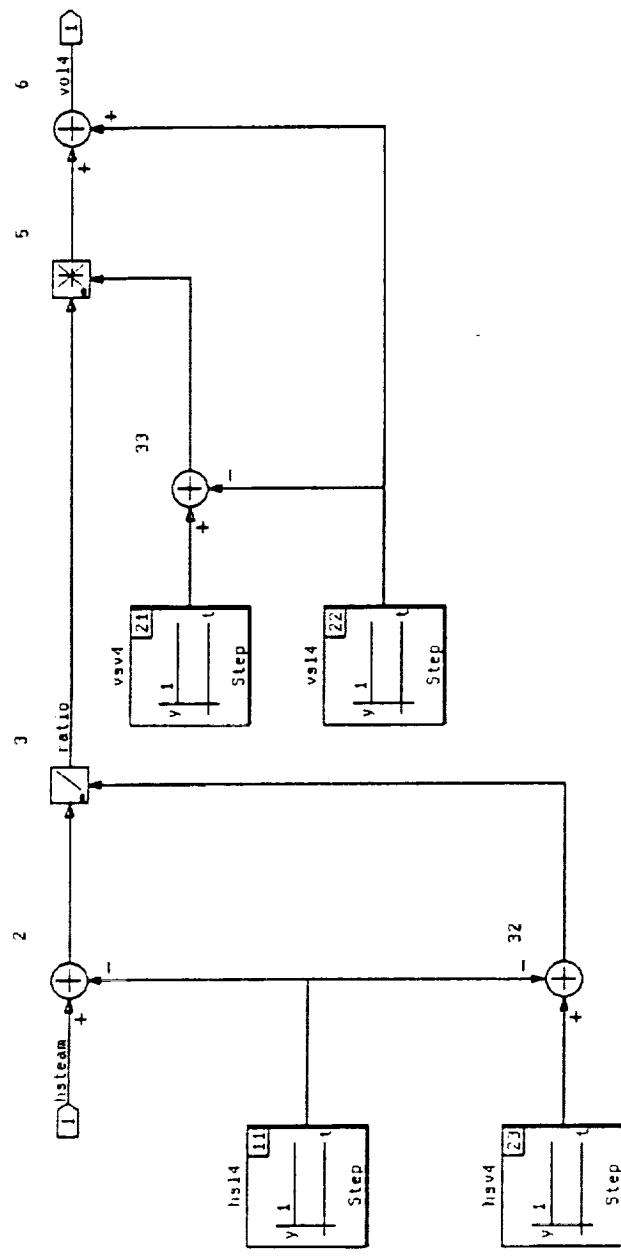
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
vol3 1 1



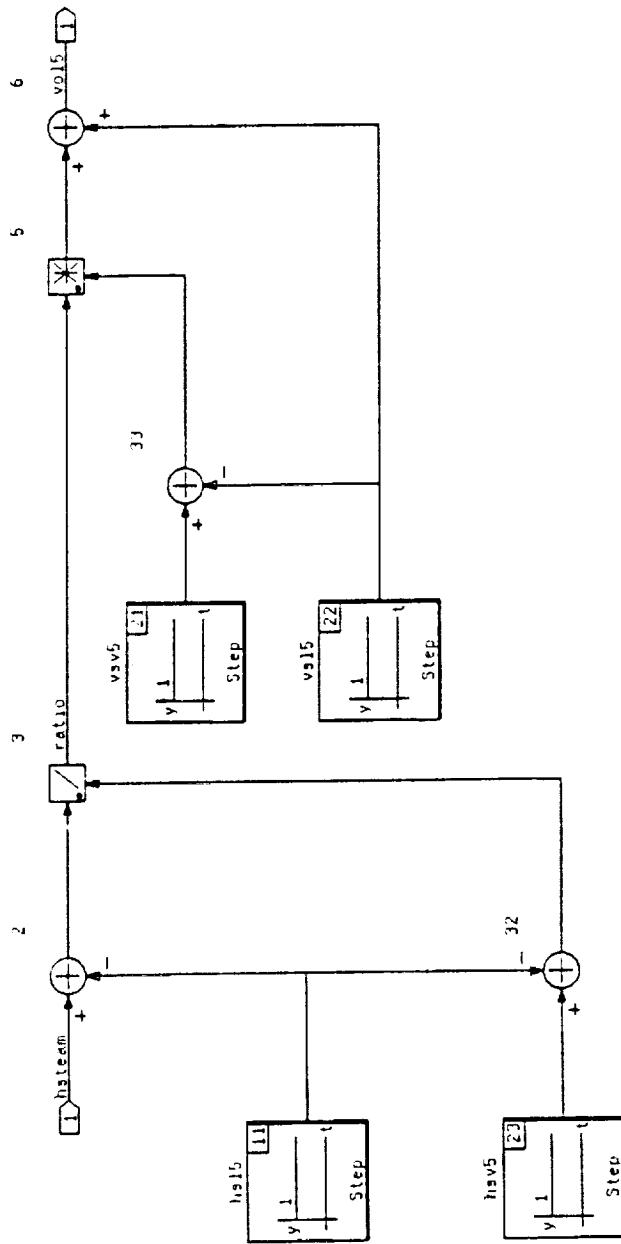
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
vol4 1 1



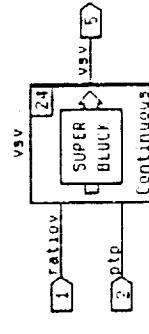
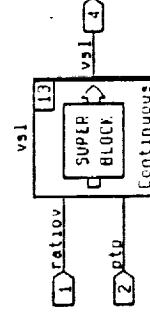
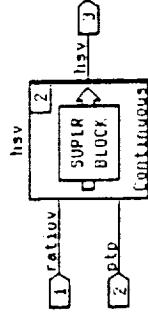
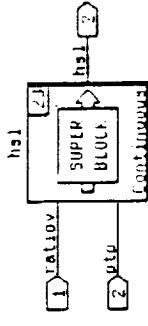
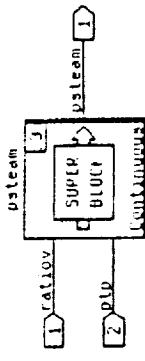
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
vol5 1 1



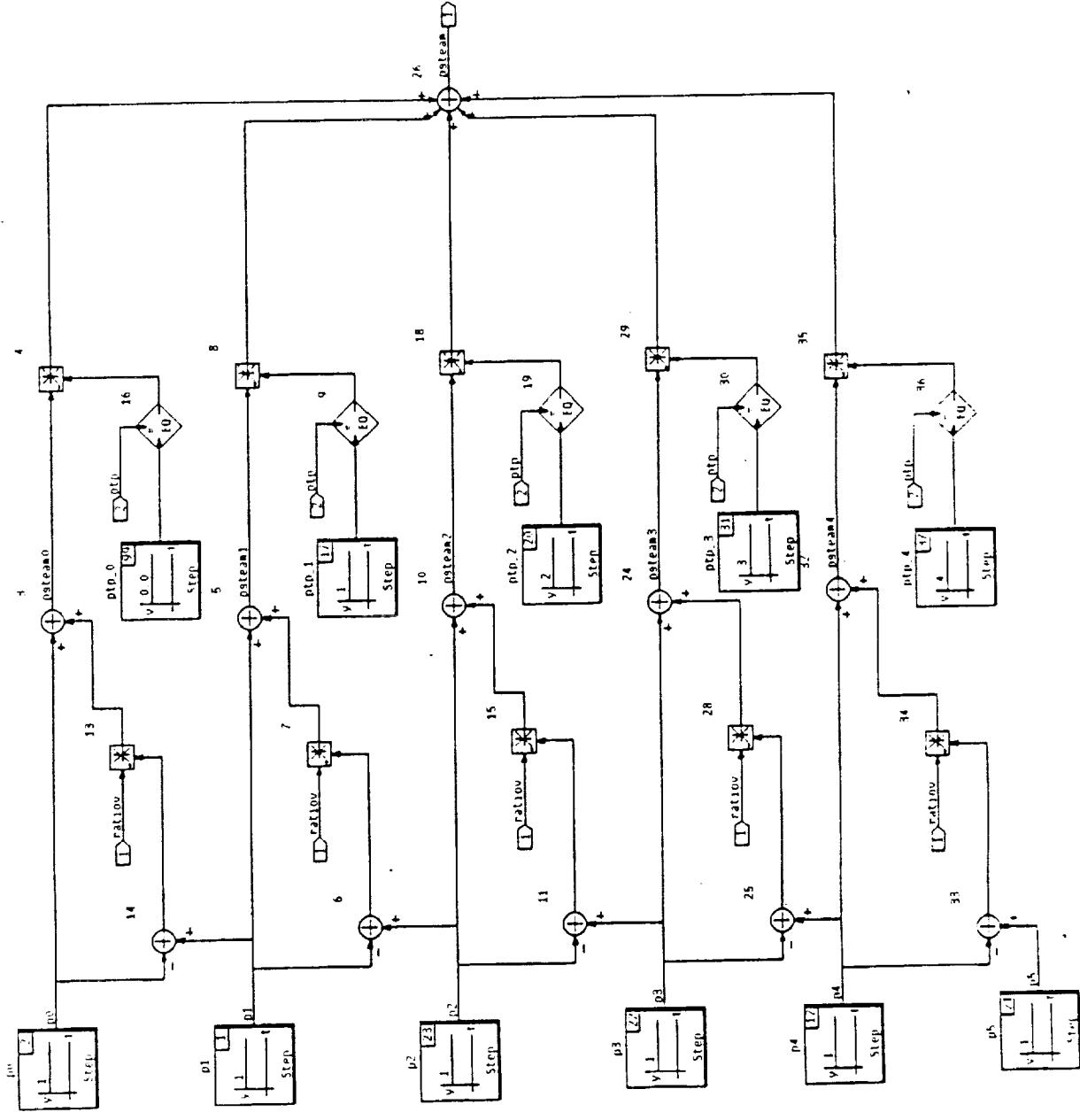
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
p and hs1 2 5



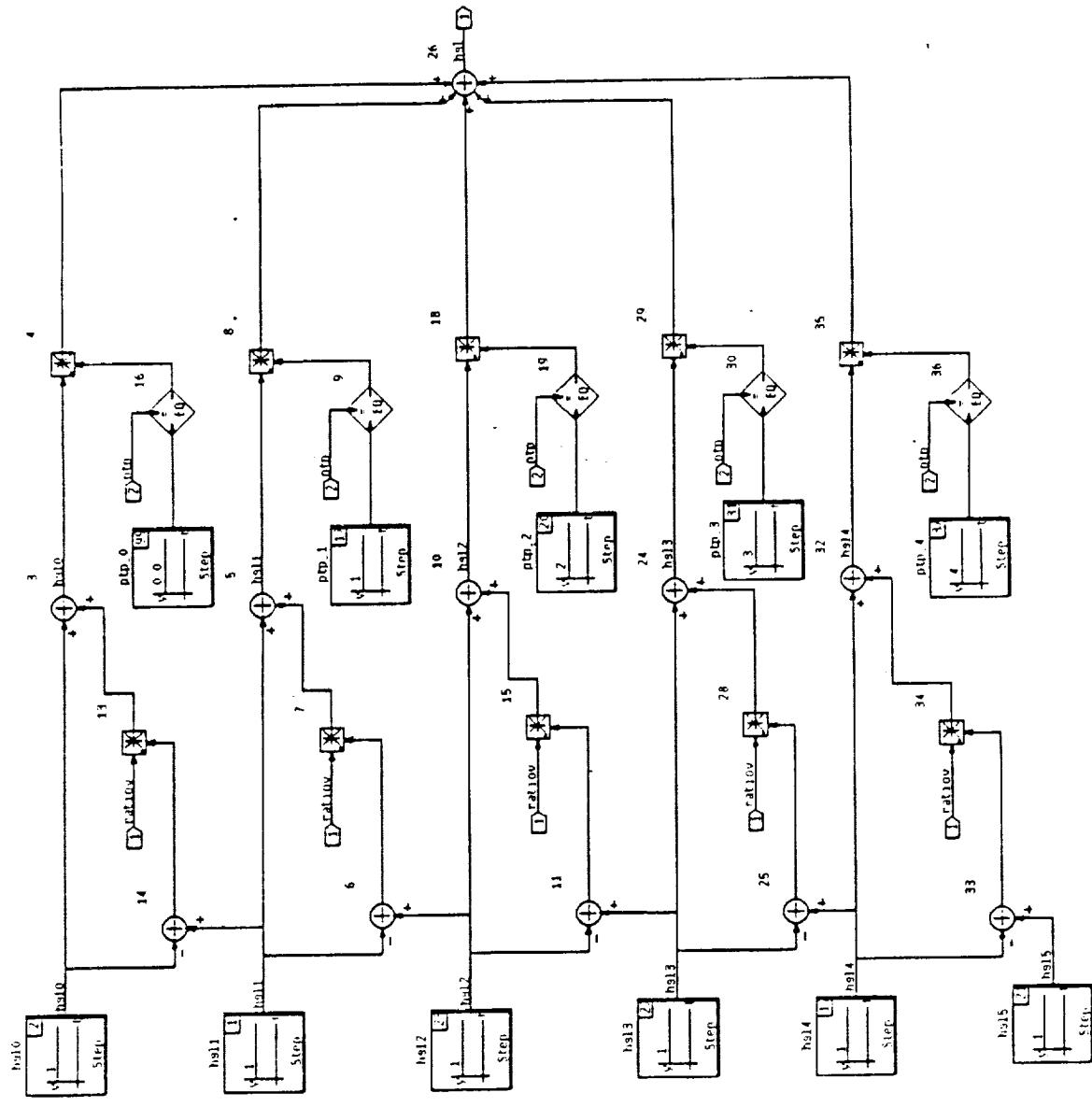
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
 psteam 2 1



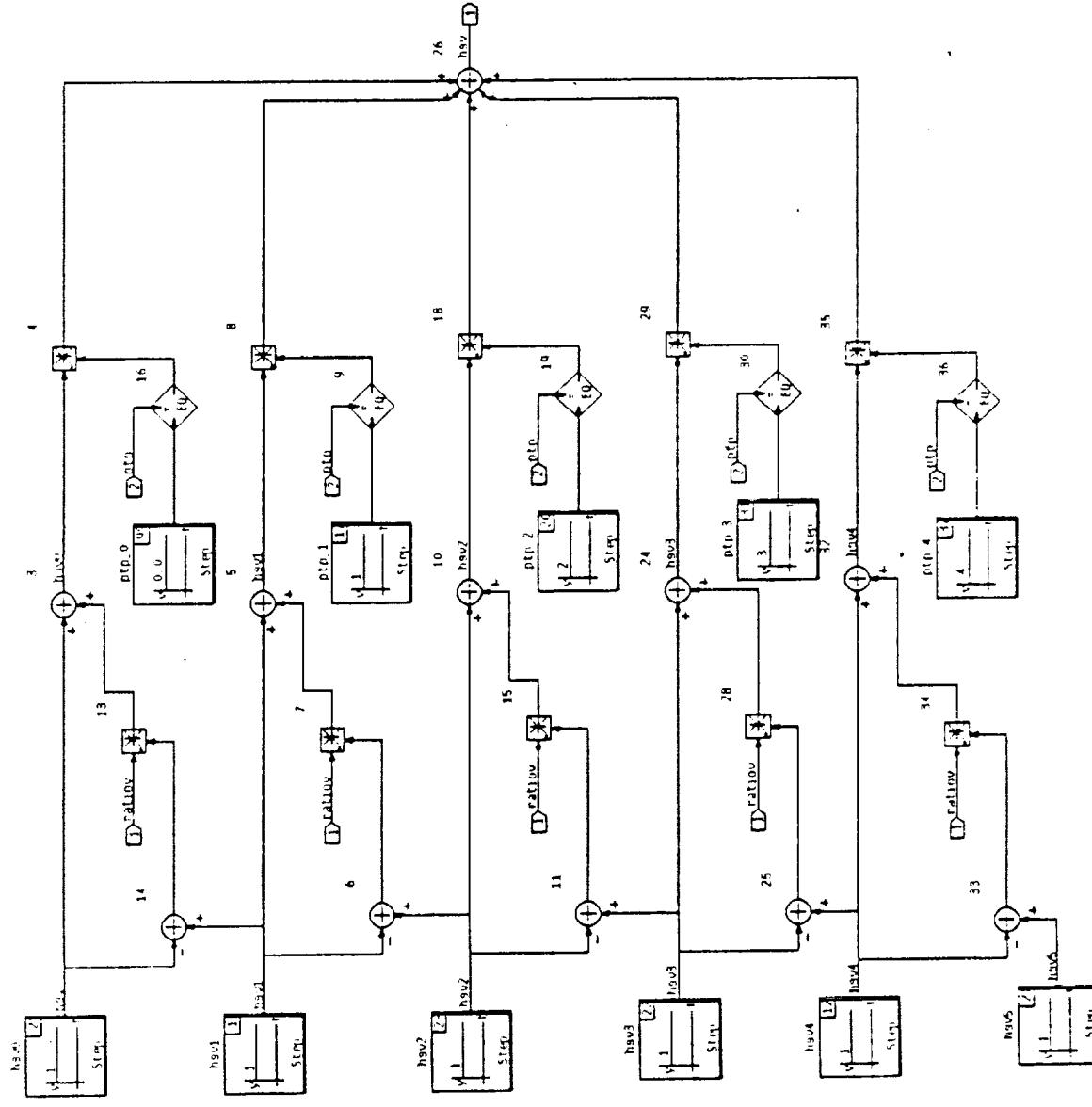
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
 hsl1 2 1



HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
 h_{sv} 2 1

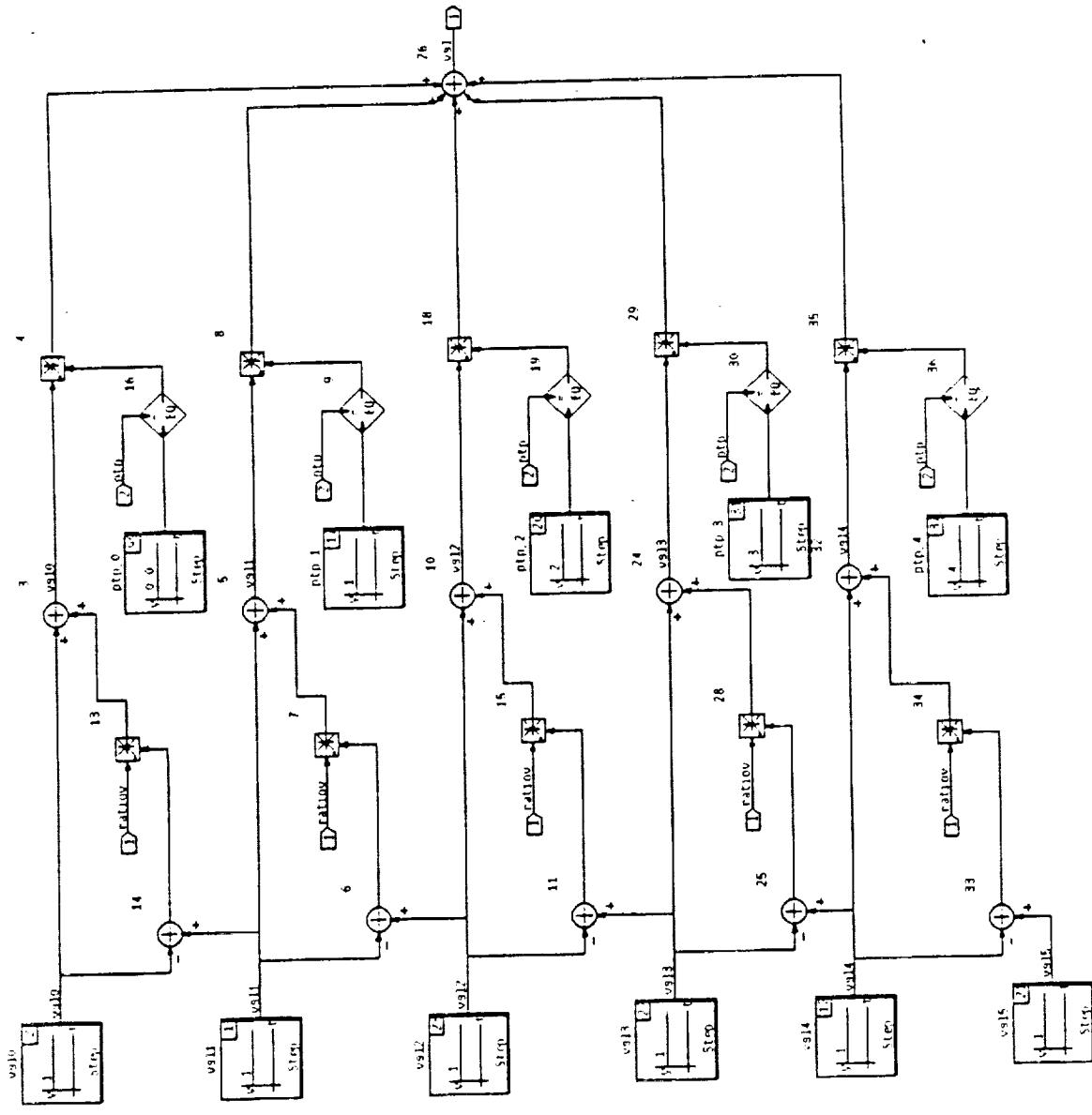


HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs

2

1

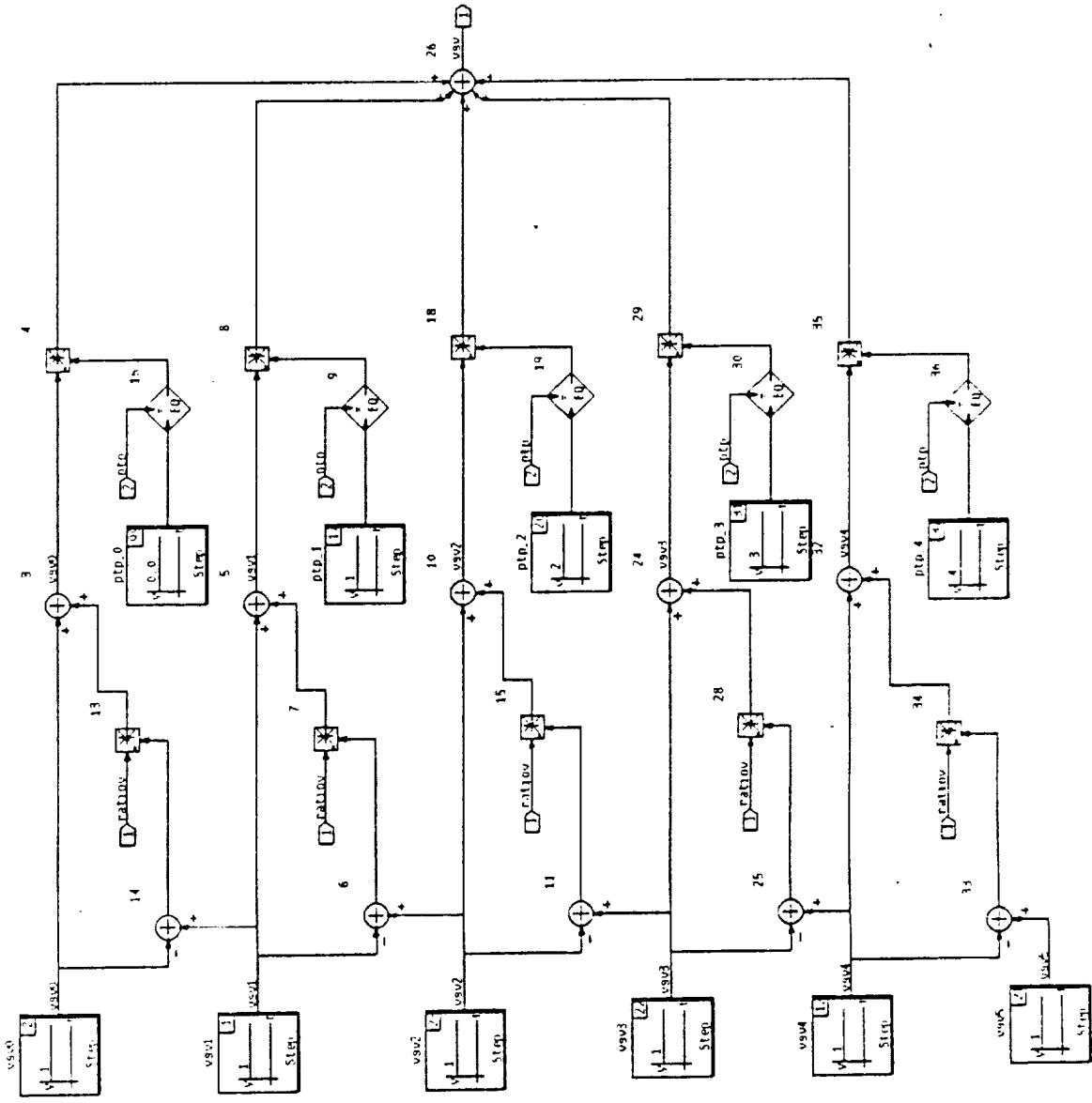


HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs

\dot{z}

1

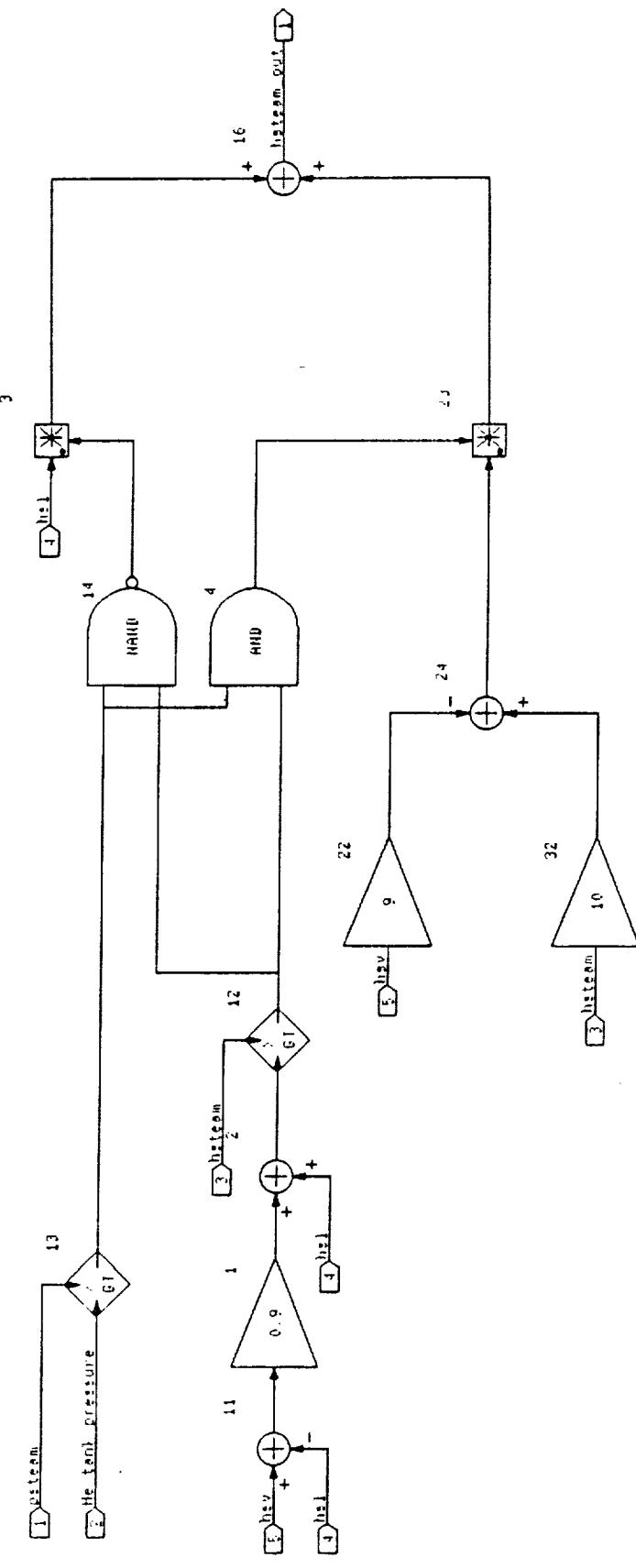


HINTS

Continuous_Super-Block
Heterom_out

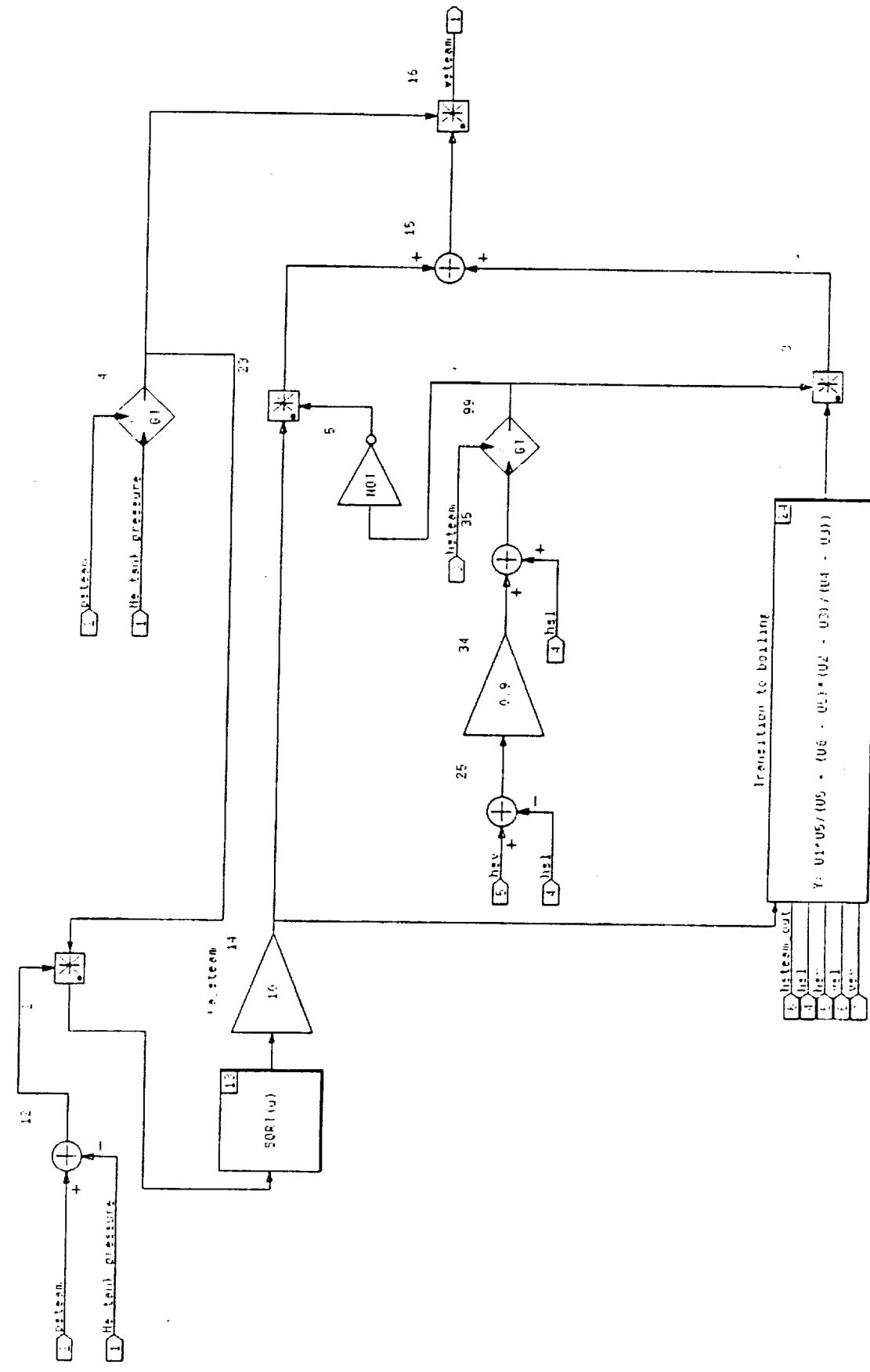
Ext. Inputs Ext. Outputs

G1



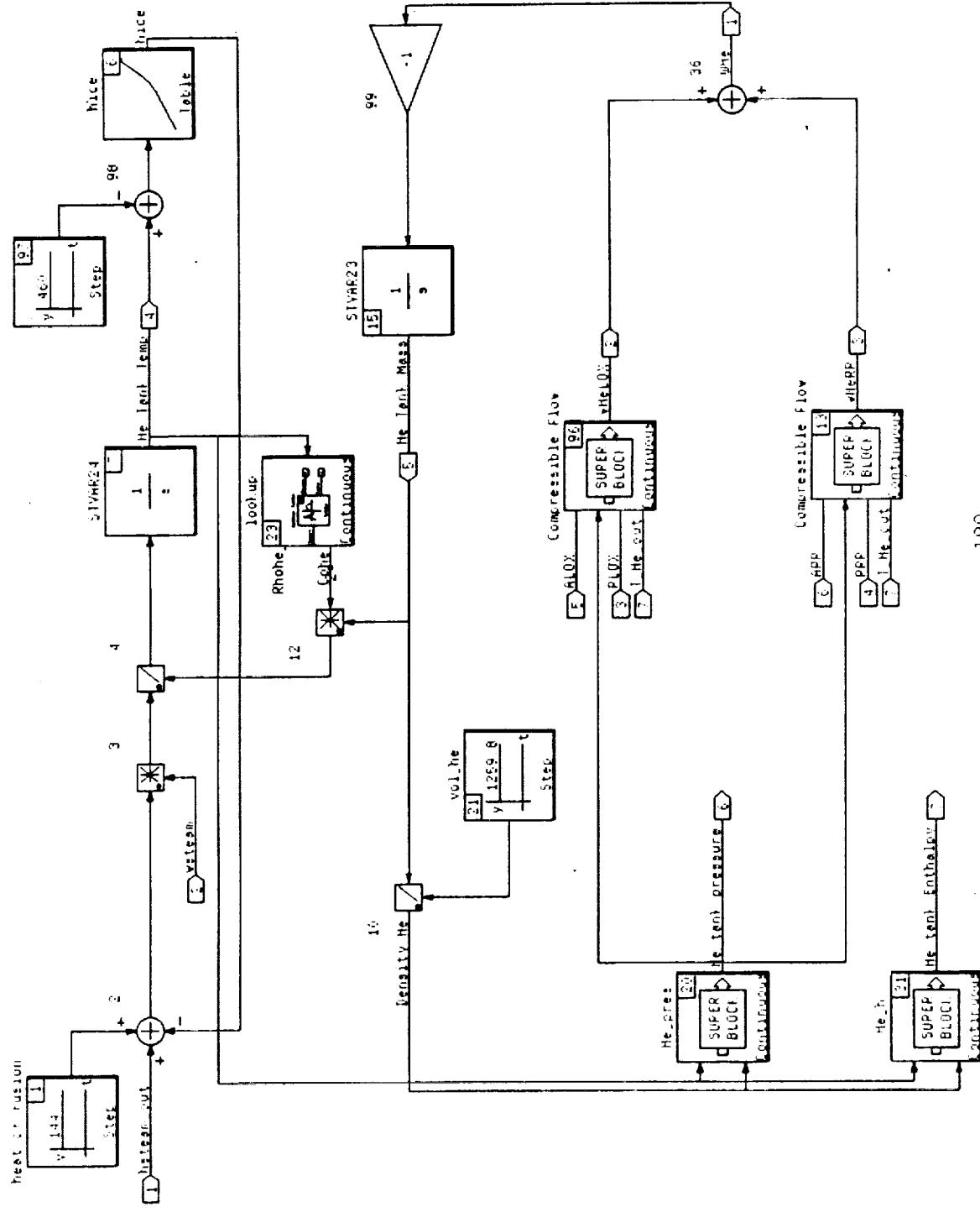
HINTS

Control valves: External - External
Ext. Inputs: Ext. Outputs: 1



HINTS

Continuous Super-Block
Helium Engine
Ext. Inputs Ext. Outputs



HINTS

Continuous Super-Block
He_pres

Ext. Inputs Ext. Outputs

1

2

ρ_{100} : vs rho

p_1

t , rho_interp1

1. He_lant_temp

table

P1400

ρ_1

t , rho_interp2

2. He_lant_temp

table

P2

t , rho_interp3

1. He_lant_temp

table

P1800

ρ_2

t , rho_interp4

2. He_lant_temp

table

P2000

ρ_3

t , rho_interp5

1. He_lant_temp

table

P2500

ρ_4

t , rho_interp6

2. He_lant_temp

table

P3000

ρ_5

t , rho_interp7

1. He_lant_temp

table

P3500

ρ_6

t , rho_interp8

2. He_lant_temp

table

P4000

ρ_7

t , rho_interp9

1. He_lant_temp

table

P4500

ρ_8

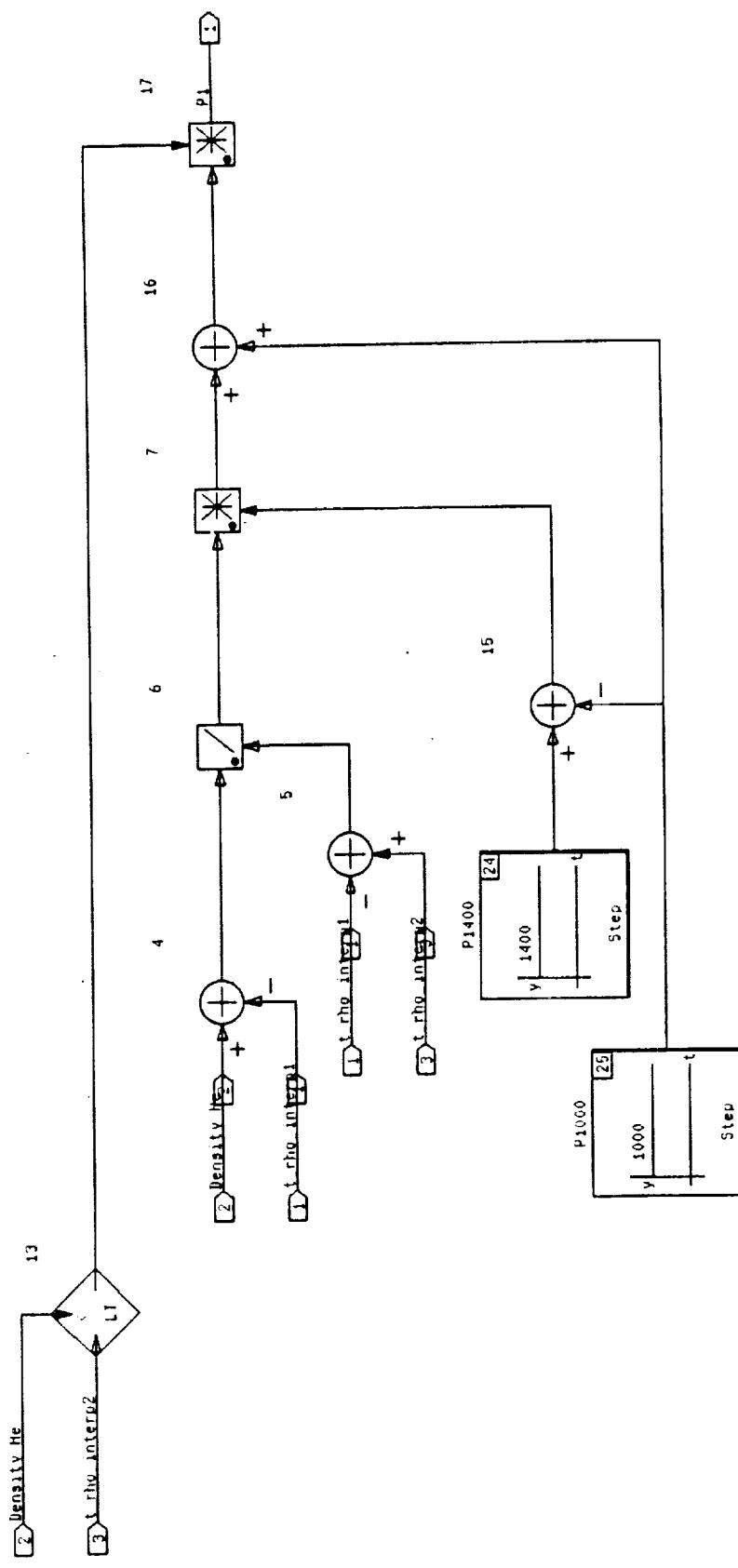
t , rho_interp10

1. He_lant_temp

table

HINTS

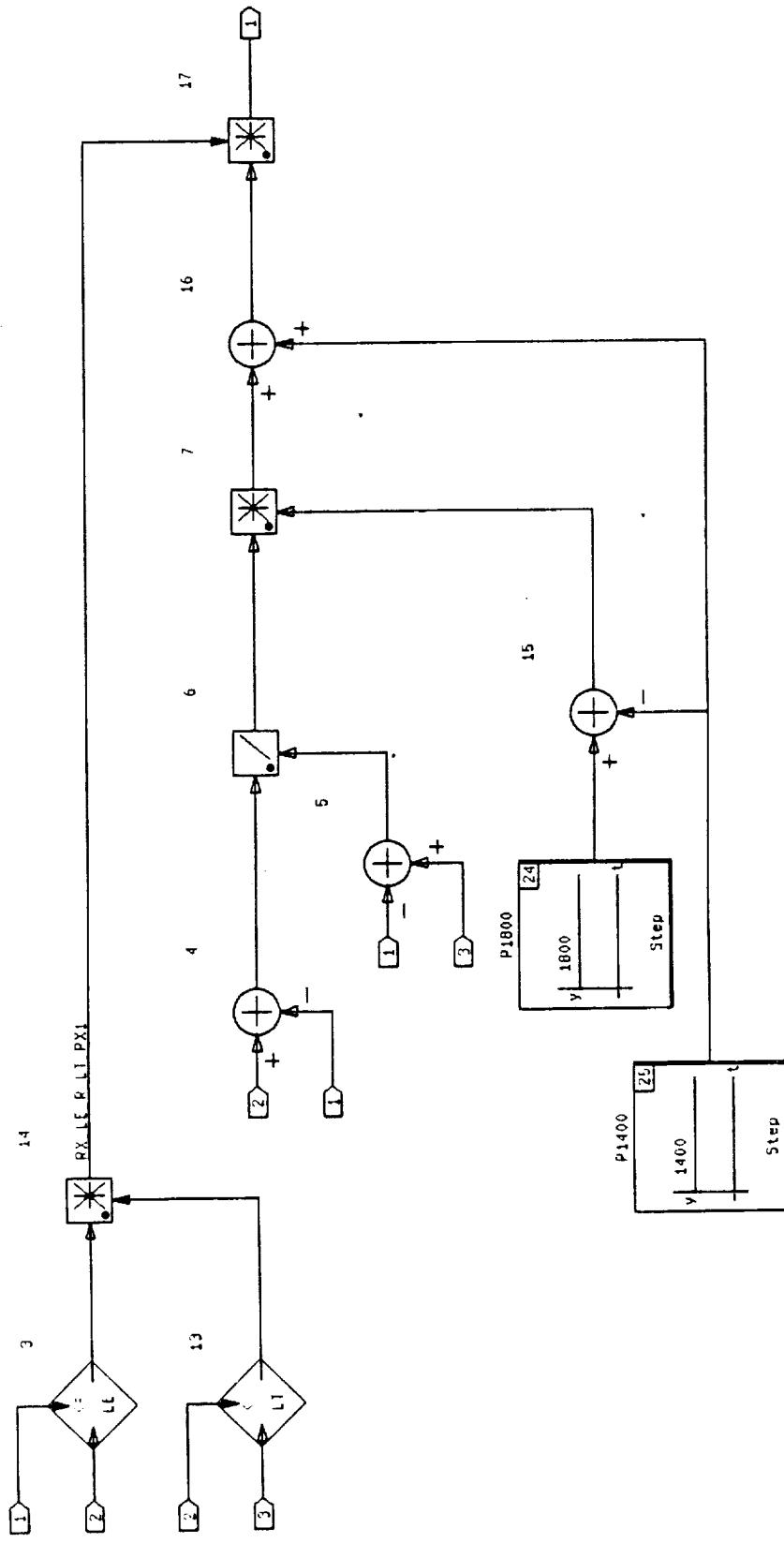
Continuous Super-Block Ext. Inputs Ext. Outputs
P1 3 1



HINTS

Continuous Super-Block P2

Ext. Inputs 3 Ext. Outputs 1

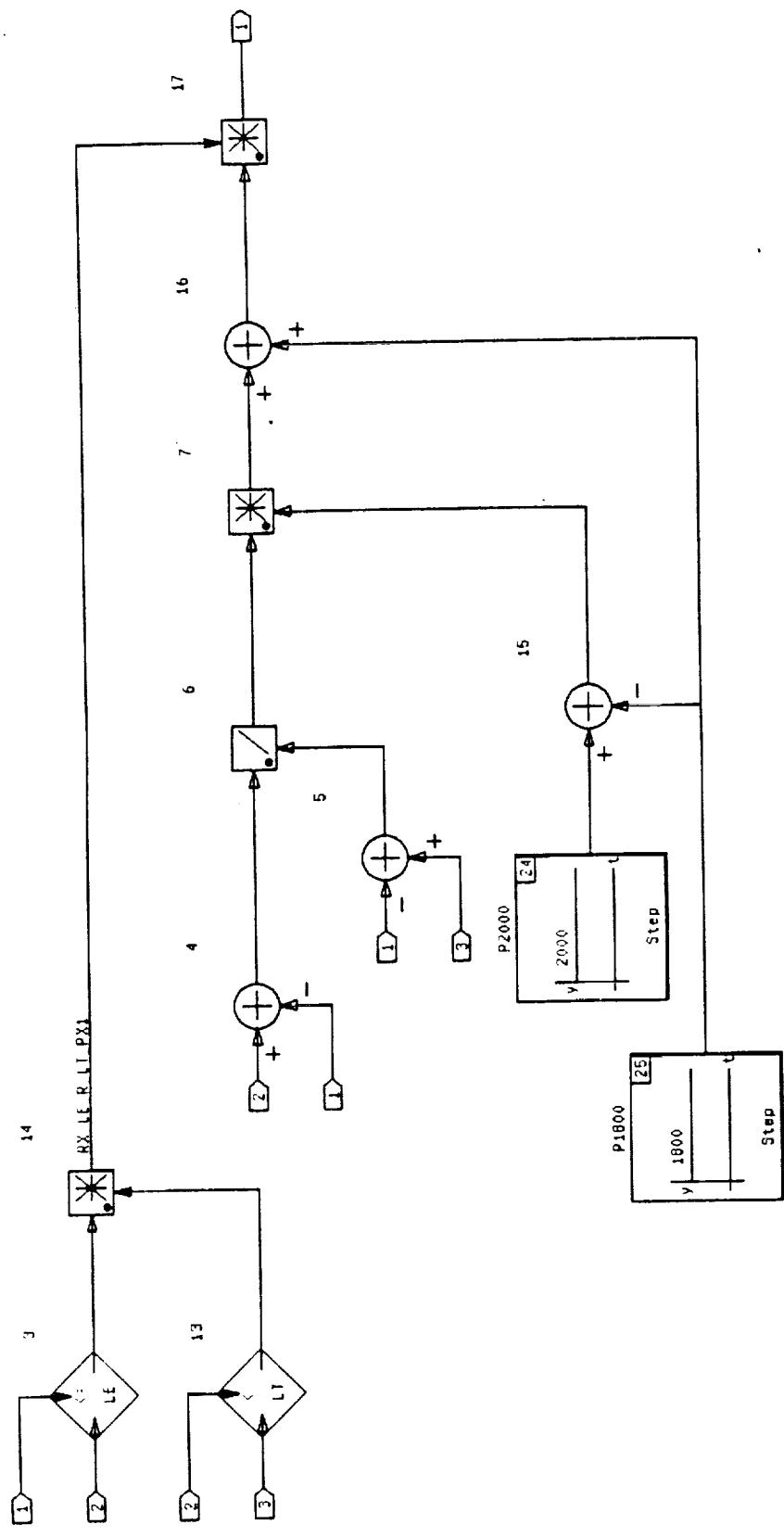


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63

HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
P3 3 1

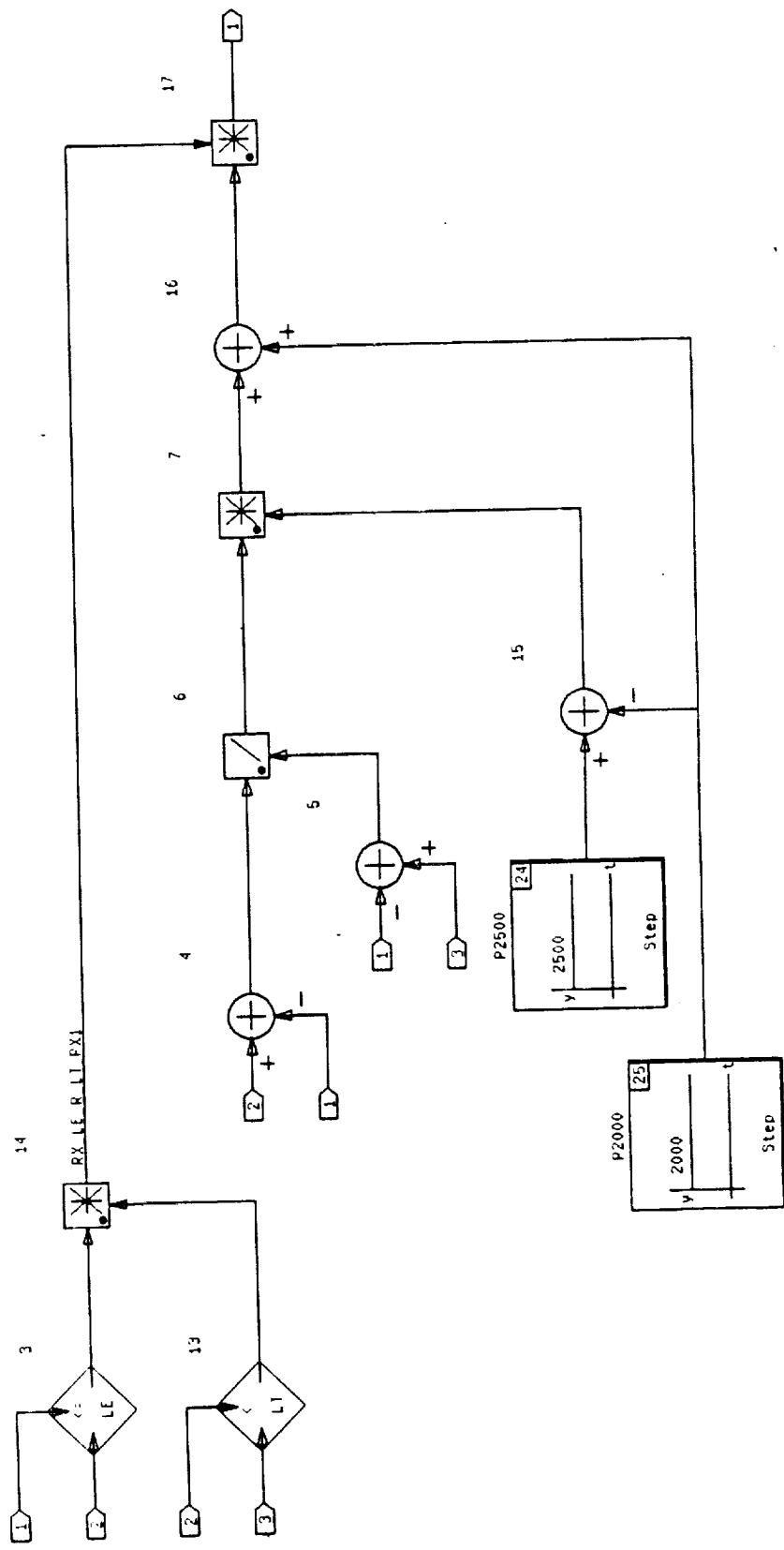


HINTS

Continuous Super-Block
P4

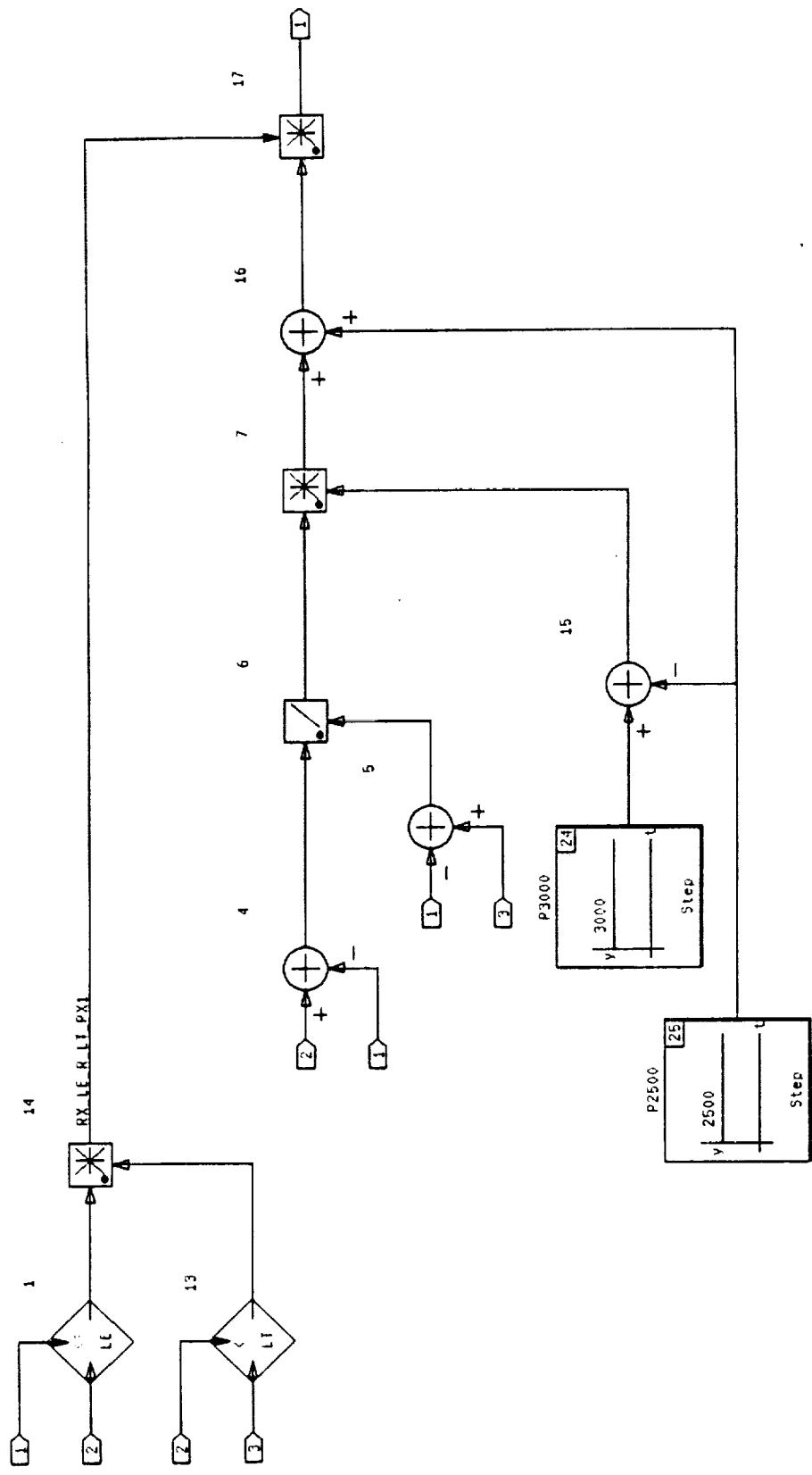
Ext. Inputs Ext. Outputs

1



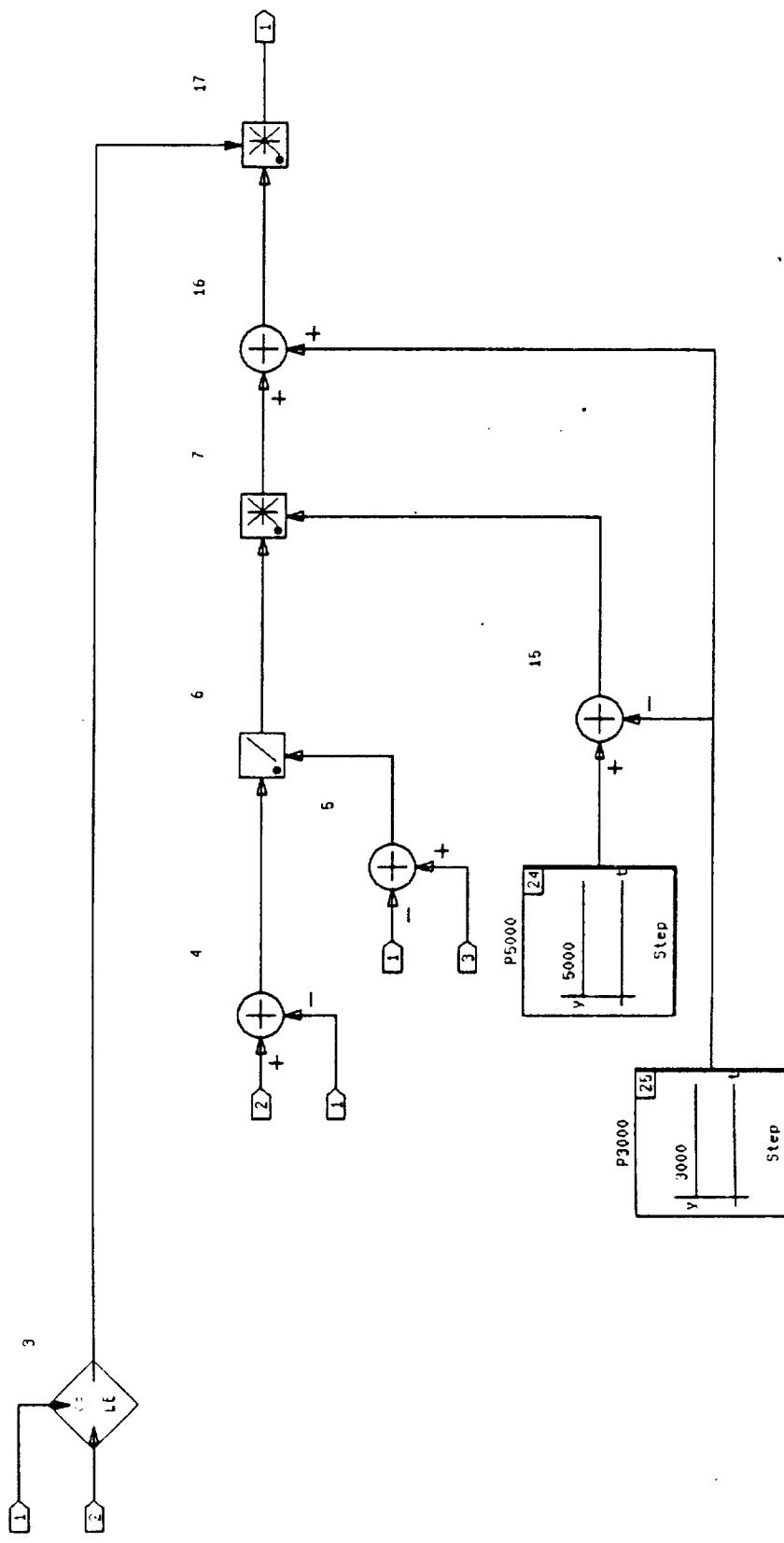
HINTS

Continuous Super-Block
PG Ext. Inputs Ext. Outputs
1 3



HINTS

Continuous Super-Block
P6 Ext. Inputs Ext. Outputs
3 1

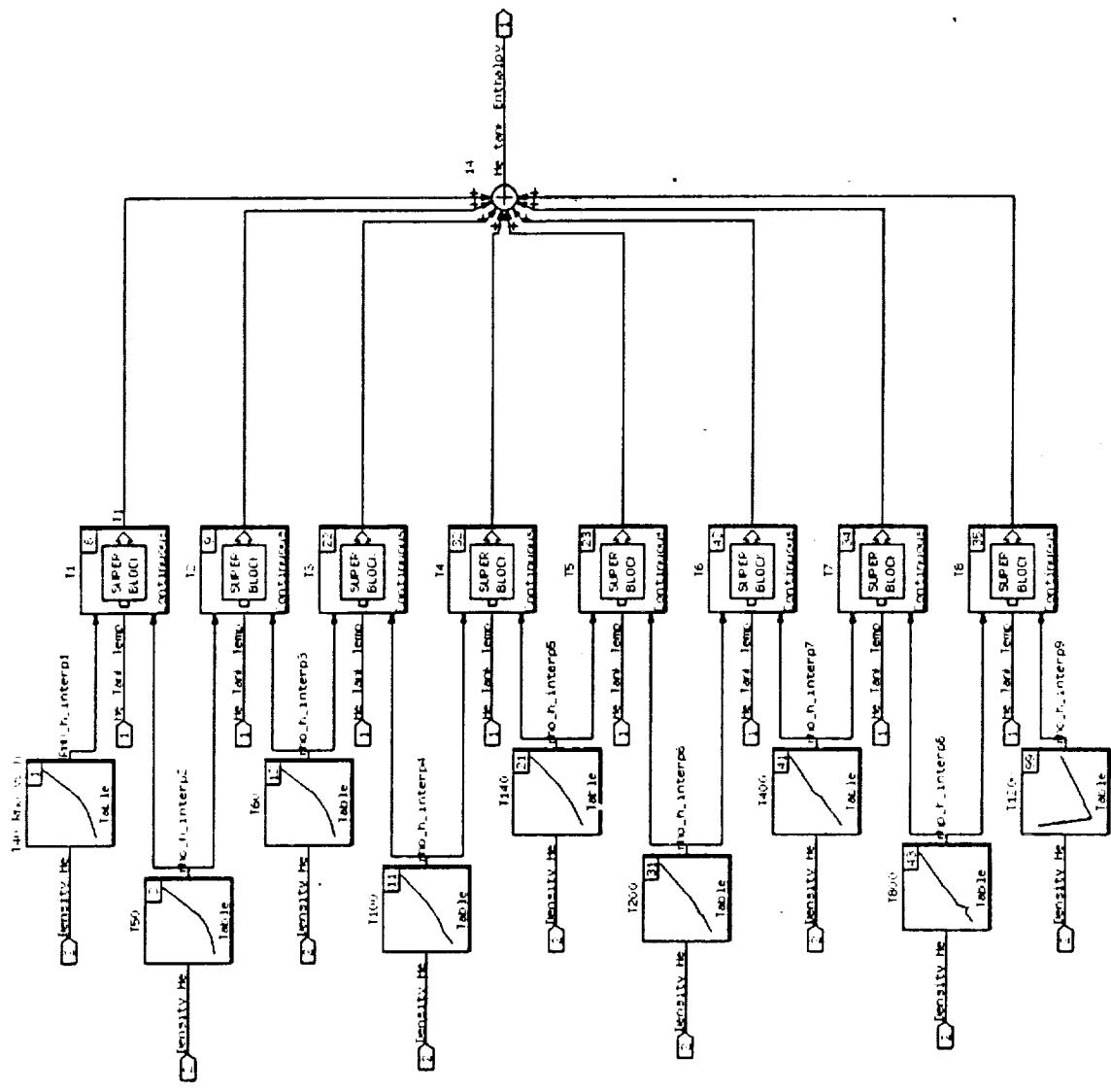


HINTS

Continuous Super-Block
He J

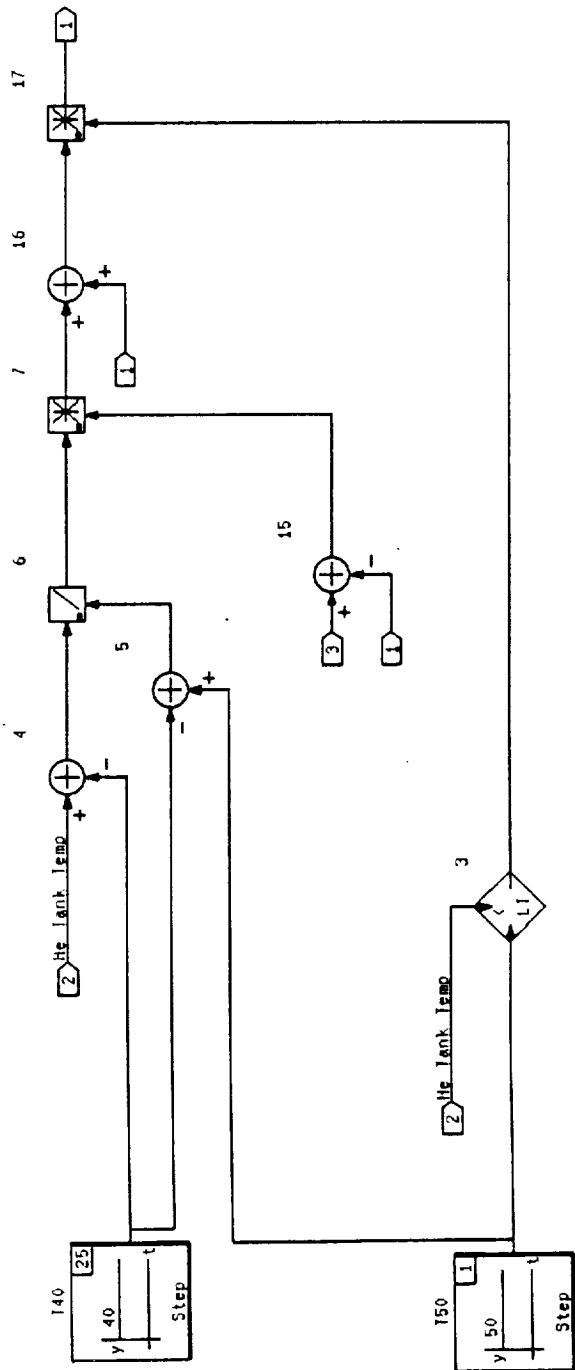
Ext. Inputs Ext. Outputs

1 2



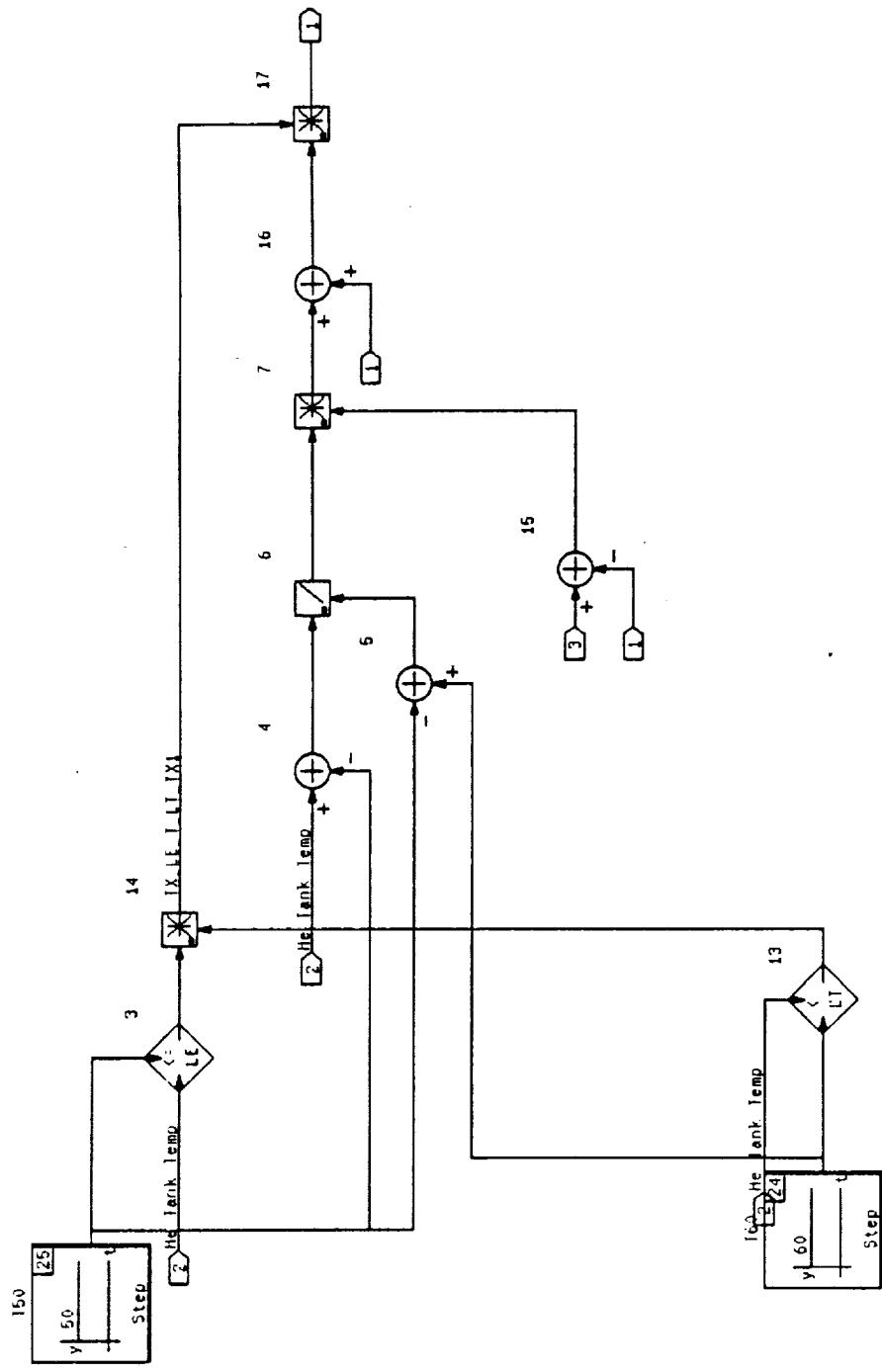
HINTS

Continuous Super-Block
T1 Ext. Inputs Ext. Outputs
3 1



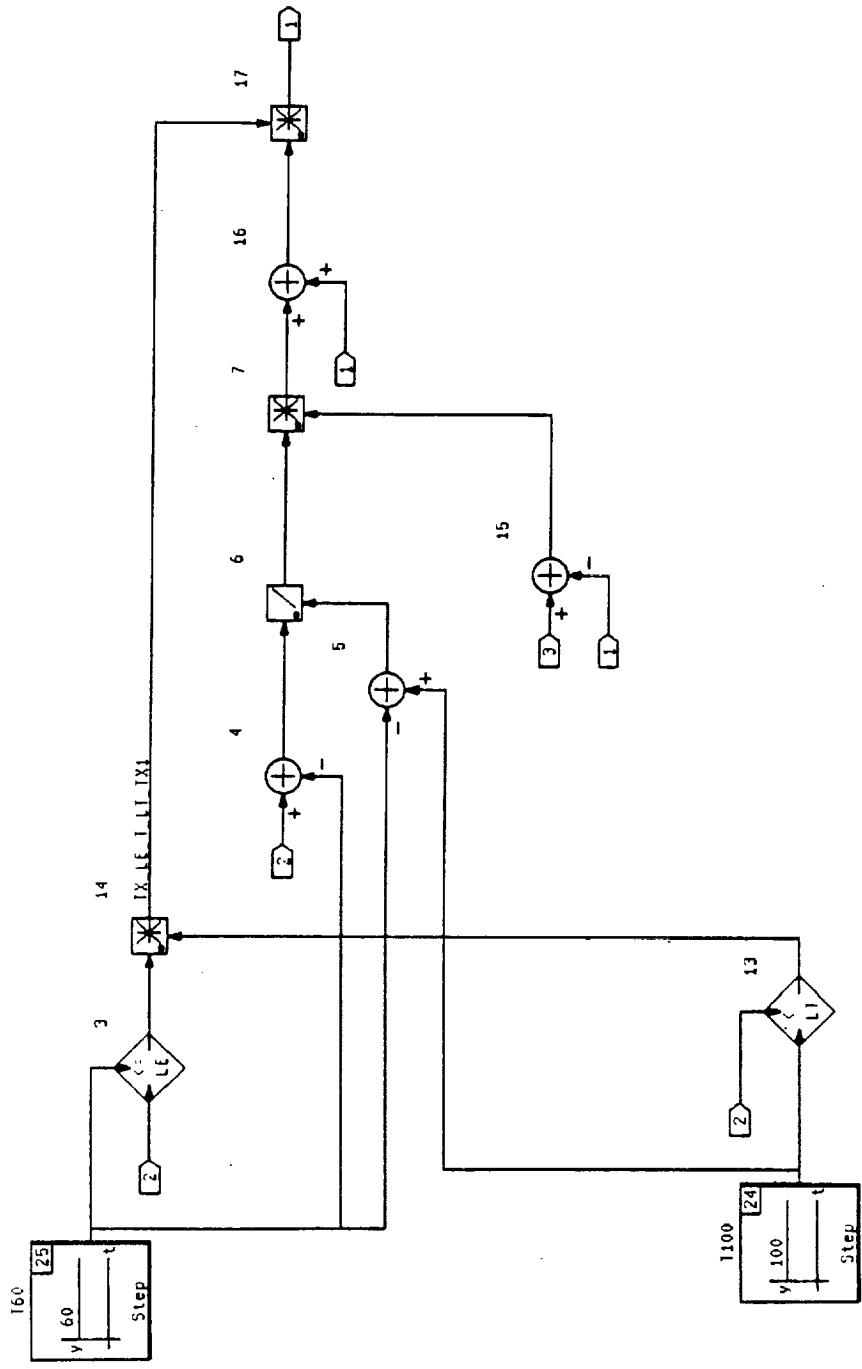
HINTS

Continuous Super-Block	Ext. Inputs	Ext. Outputs
T2	3	1



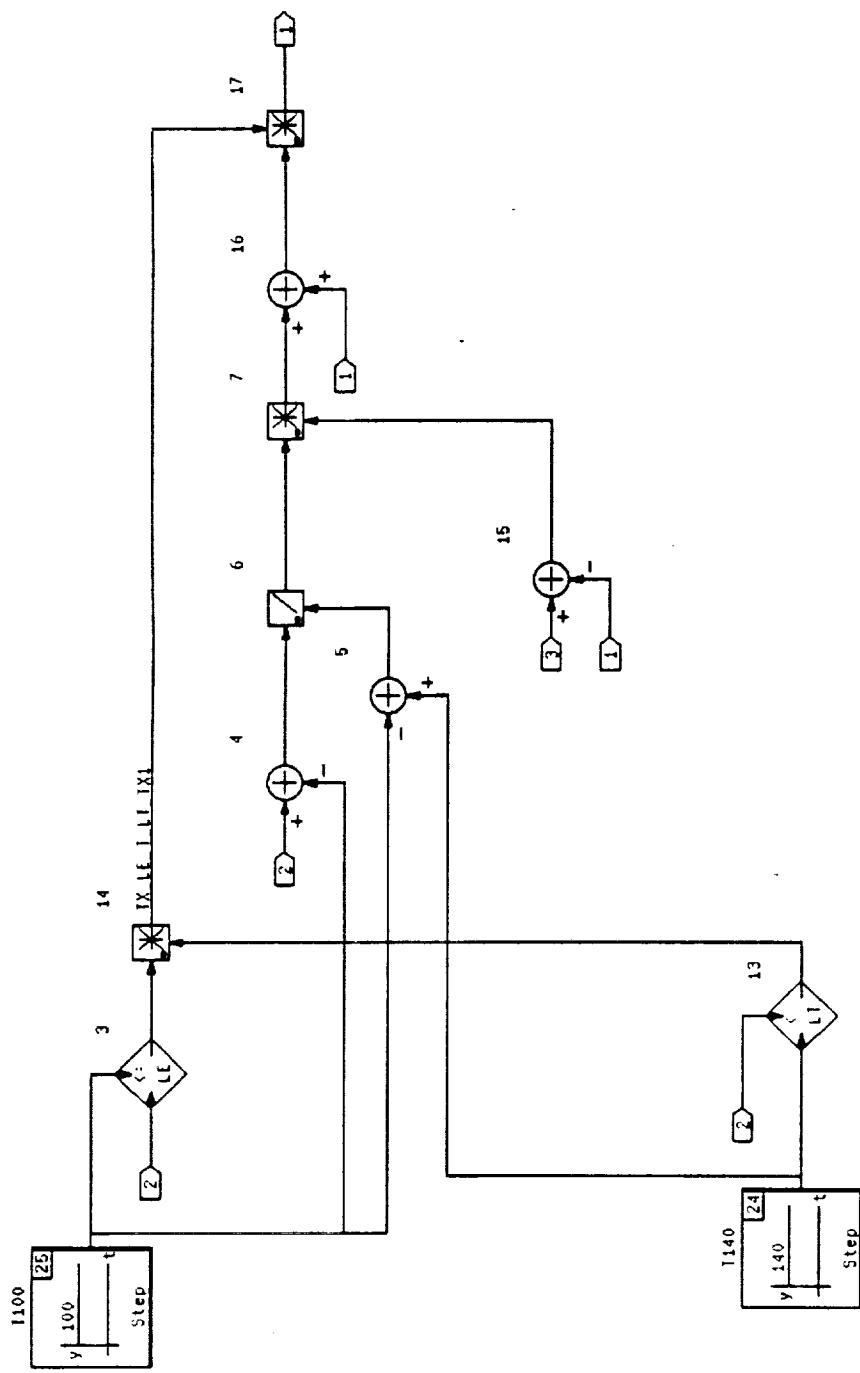
HINTS

Continuous Super-Block	Ext. Inputs	Ext. Outputs
T ₃	3	1



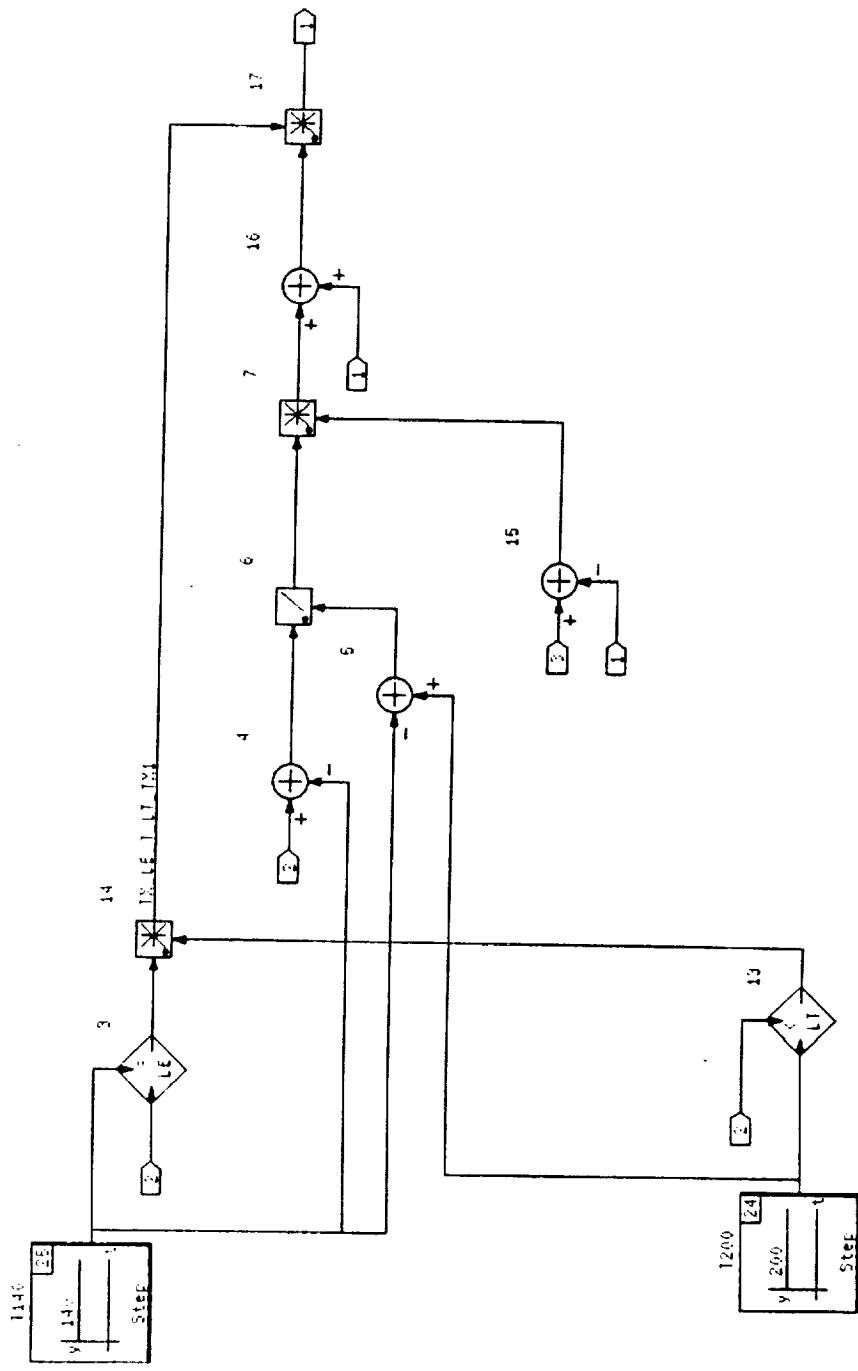
HITS

Continuous Super-Block	Ext. Inputs	Ext. Outputs
T4	3	1



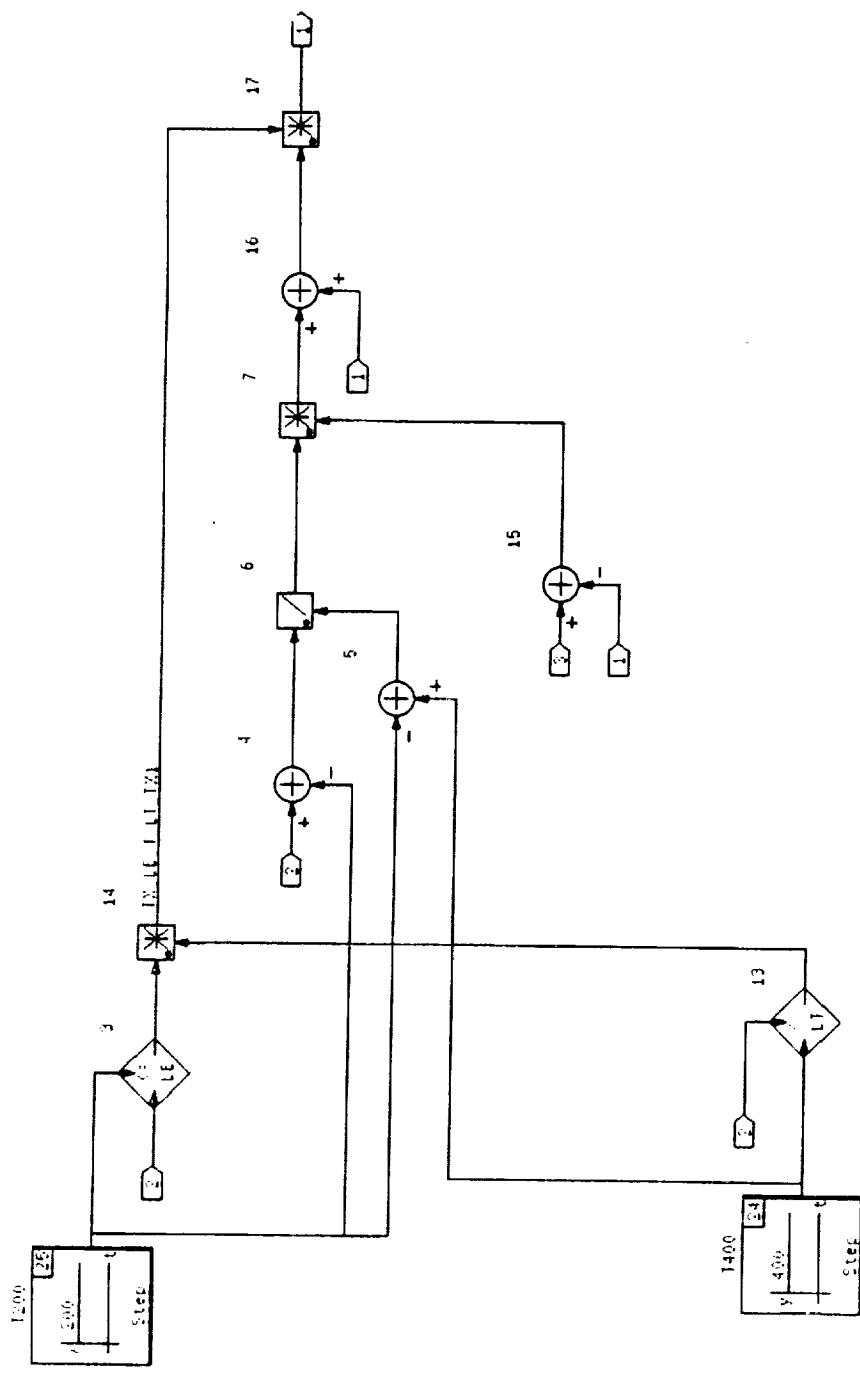
HINTS

Continuous Super-Bloc
TS Ext. Inputs Ext. Outputs
 3 1



HINTS

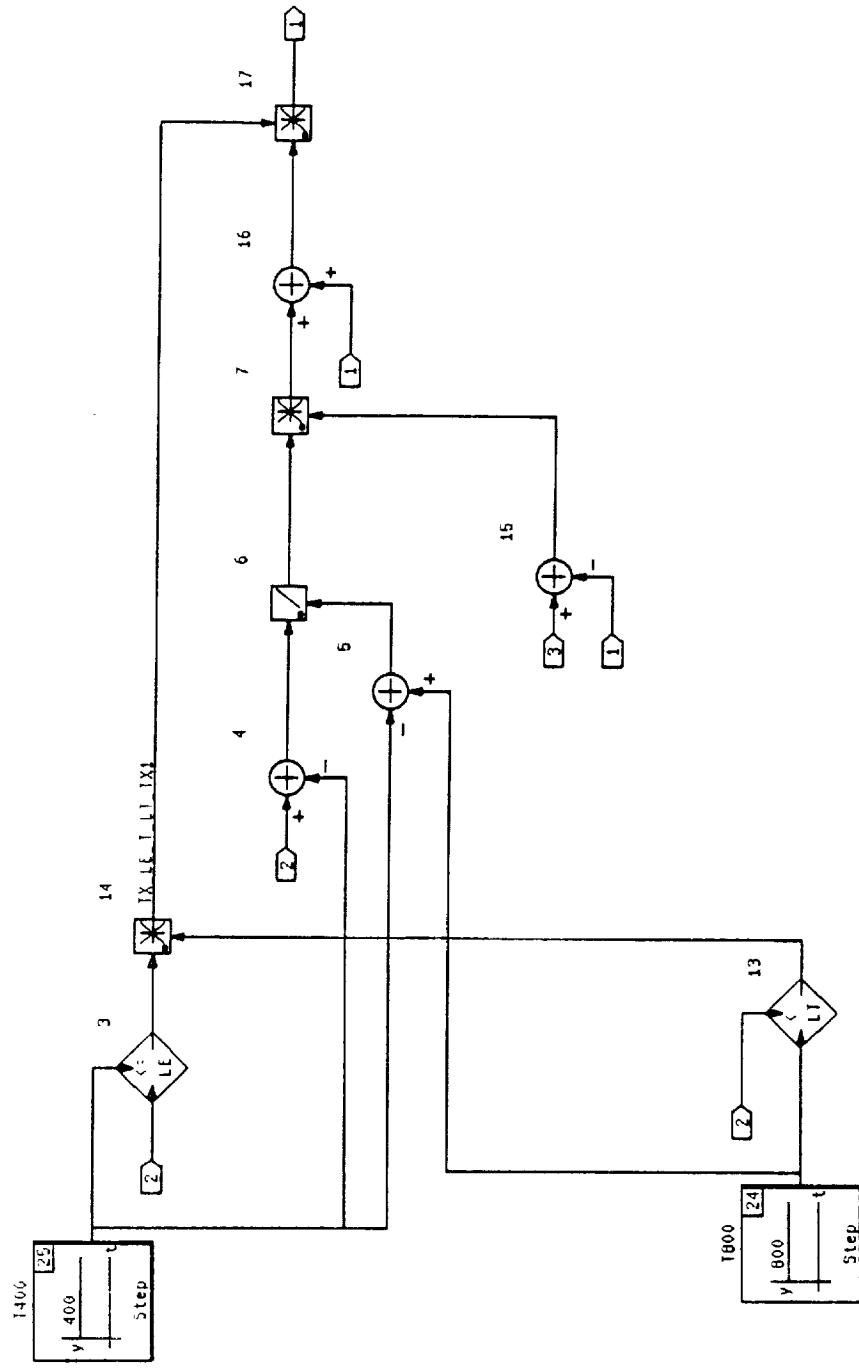
Continuous Super-Block	Ext. Inputs	Ext. Outputs
T ₆	3	1



HINTS

Continuous Super-Block
T7

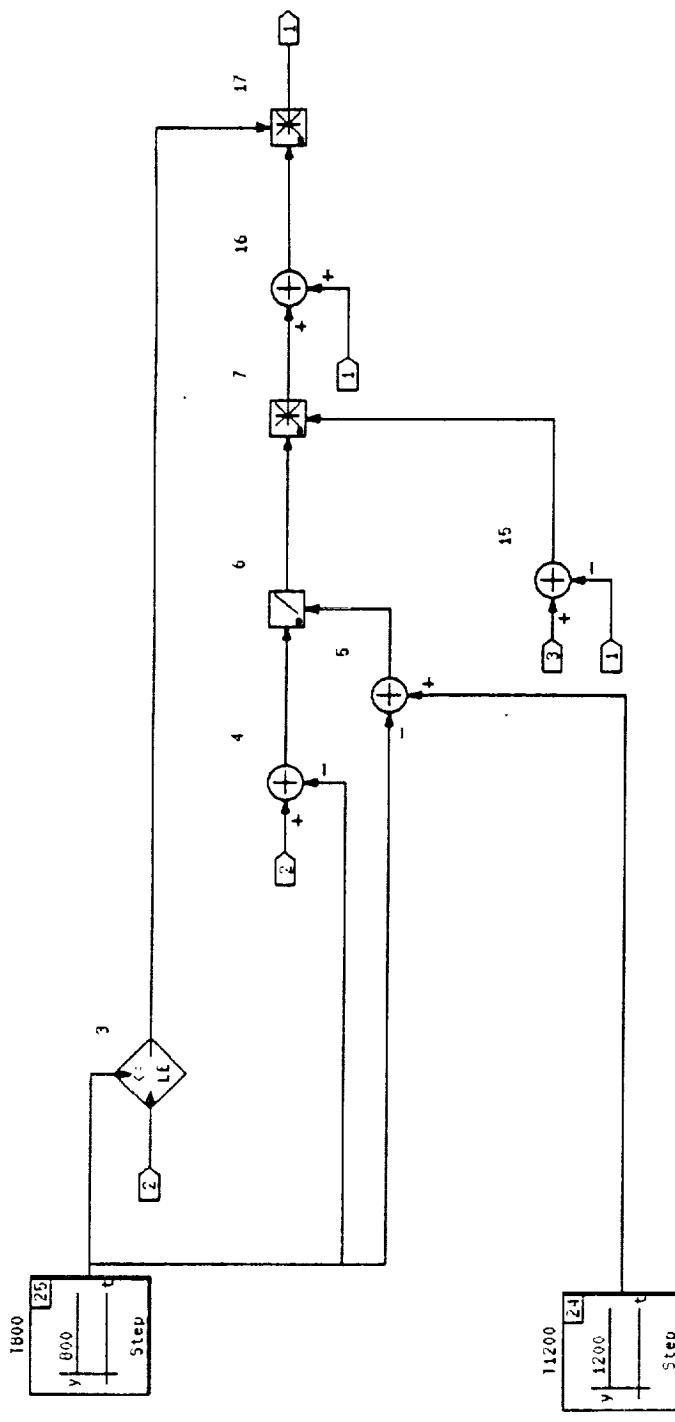
Ext. Inputs Ext. Outputs
3 1



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HINTS

Continuous Super-Block
18 Ext. Inputs Ext. Outputs
 3 1



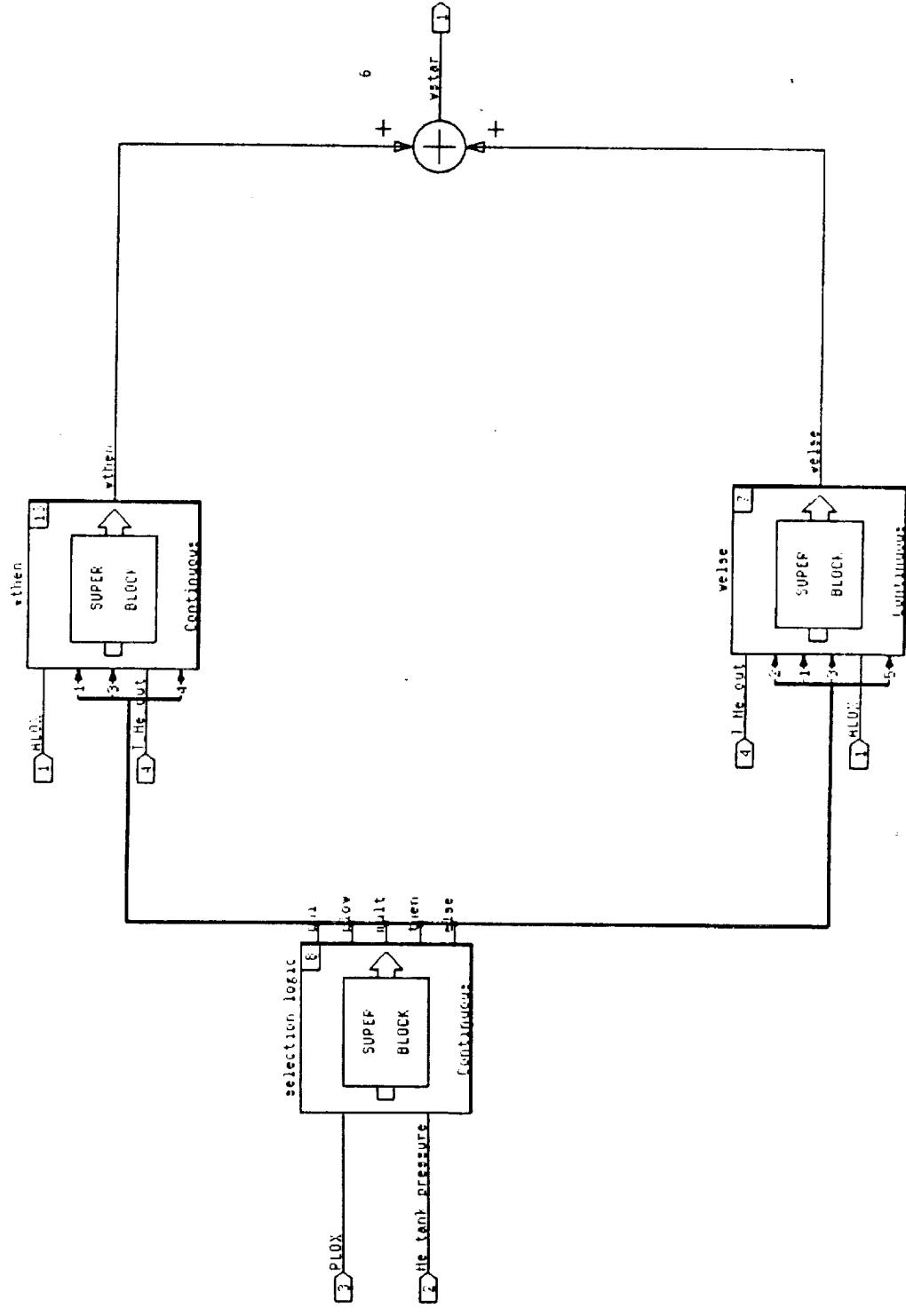
HINTS

Continuous Super-Block
Compressible Flow

Ext. Inputs Ext. Outputs

4

1



Hints

Continuous Super-Block
selection logic

Ext. Inputs Ext. Outputs

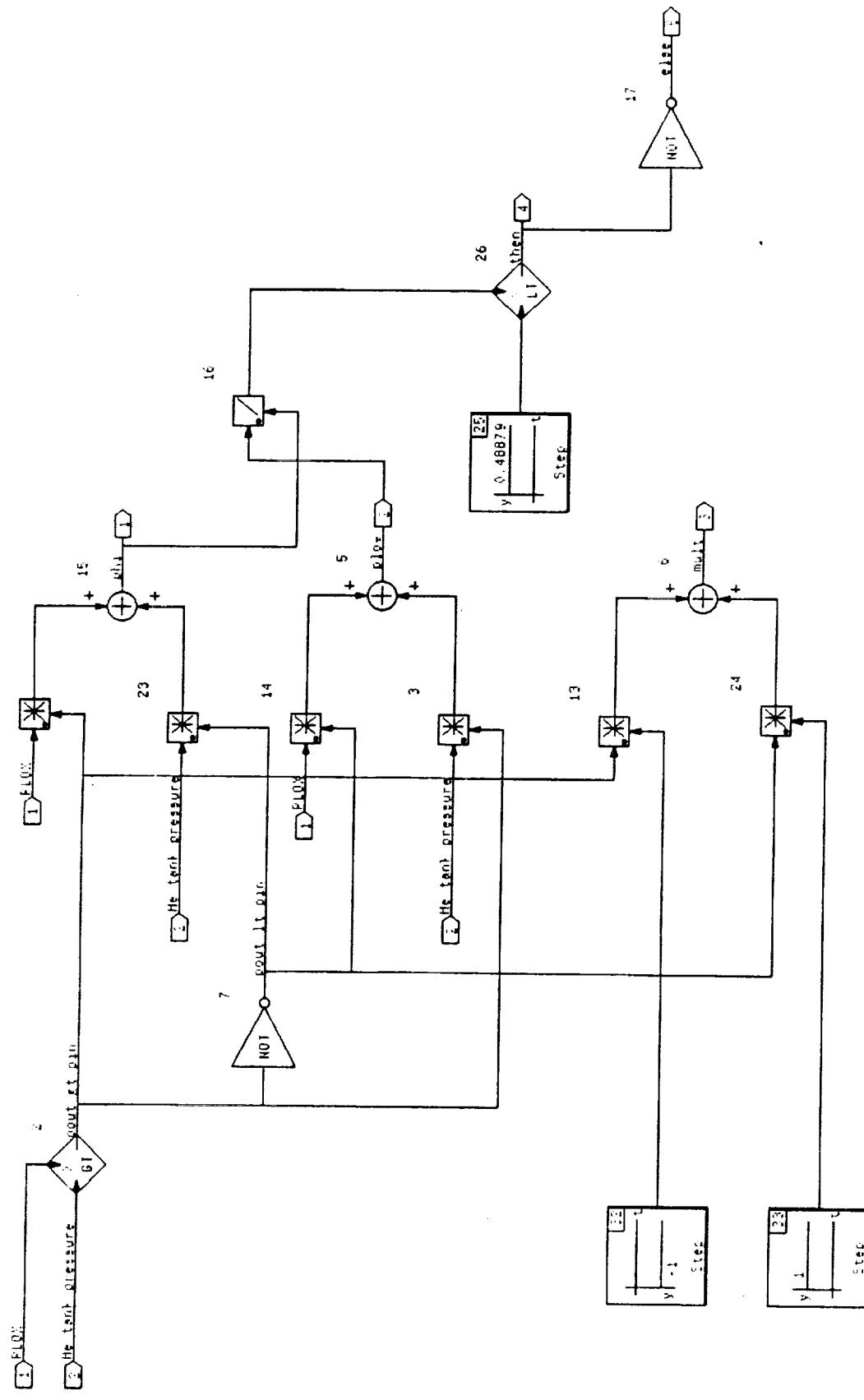
ξ_1

ξ_2

ξ_3

ξ_4

ξ_5

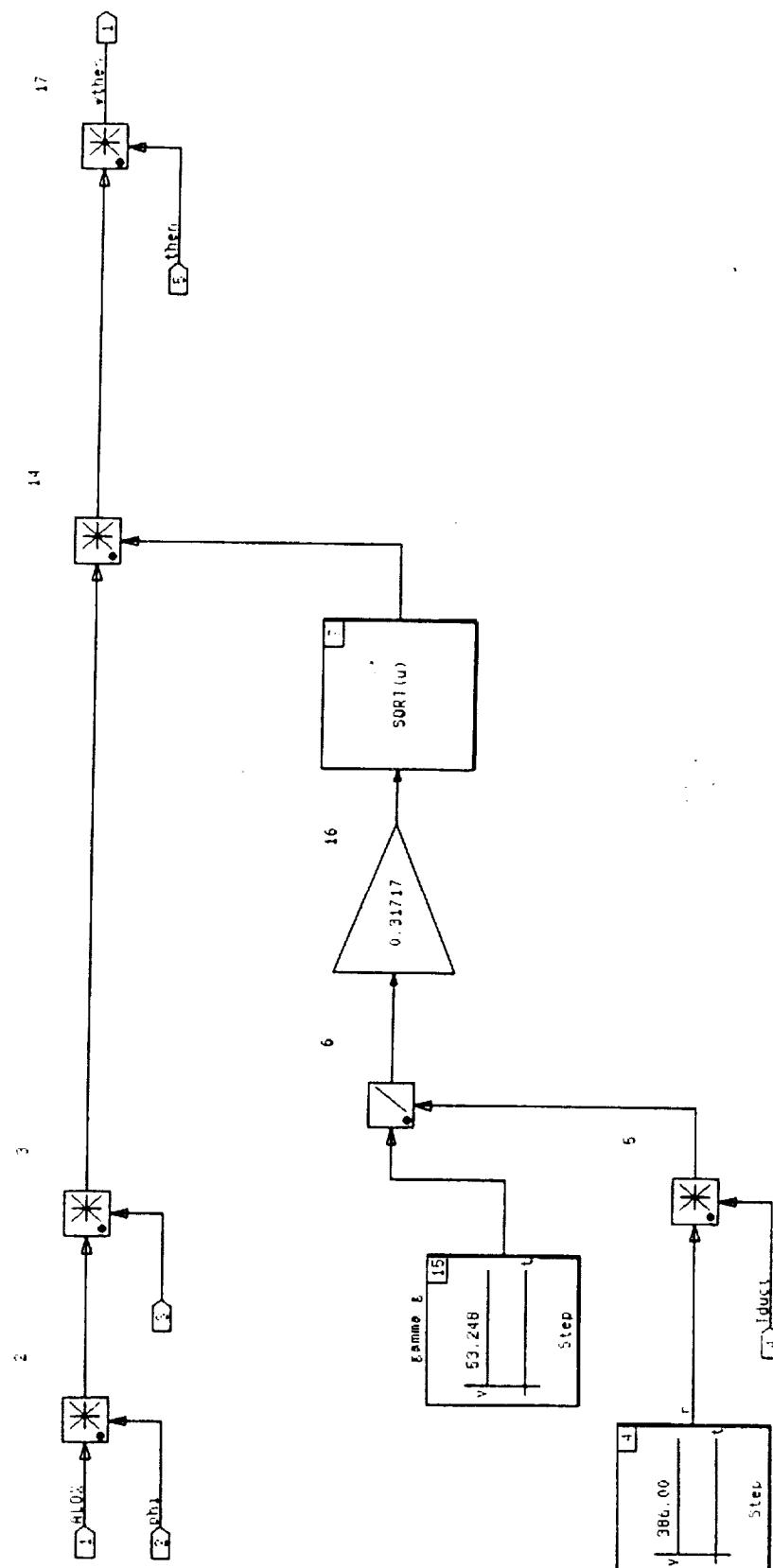


HINTS

Continuous Super-BLOCK
others

Ext. Inputs Ext. Outputs

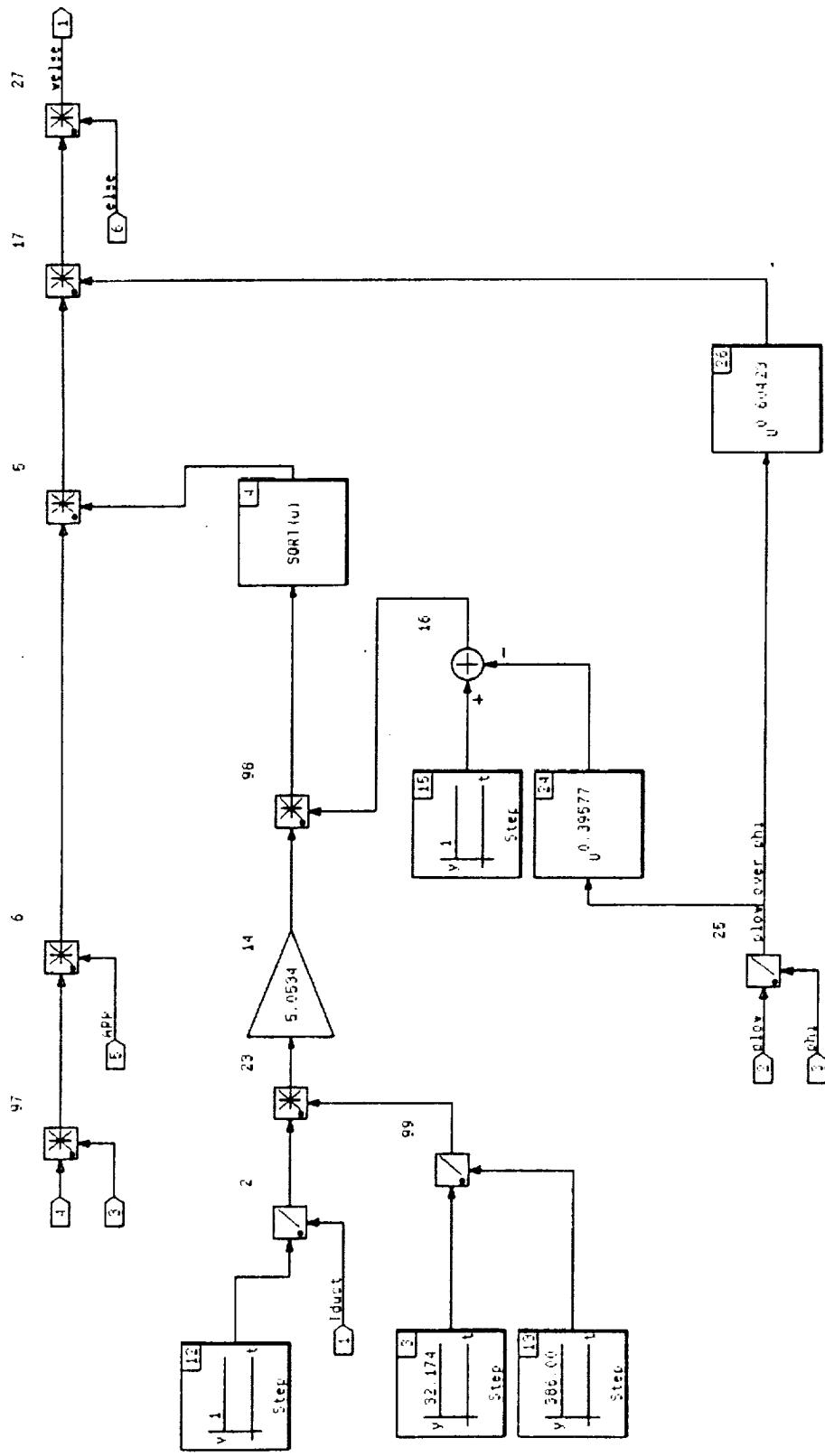
1



ORIGINAL PAGE IS
OF POOR QUALITY

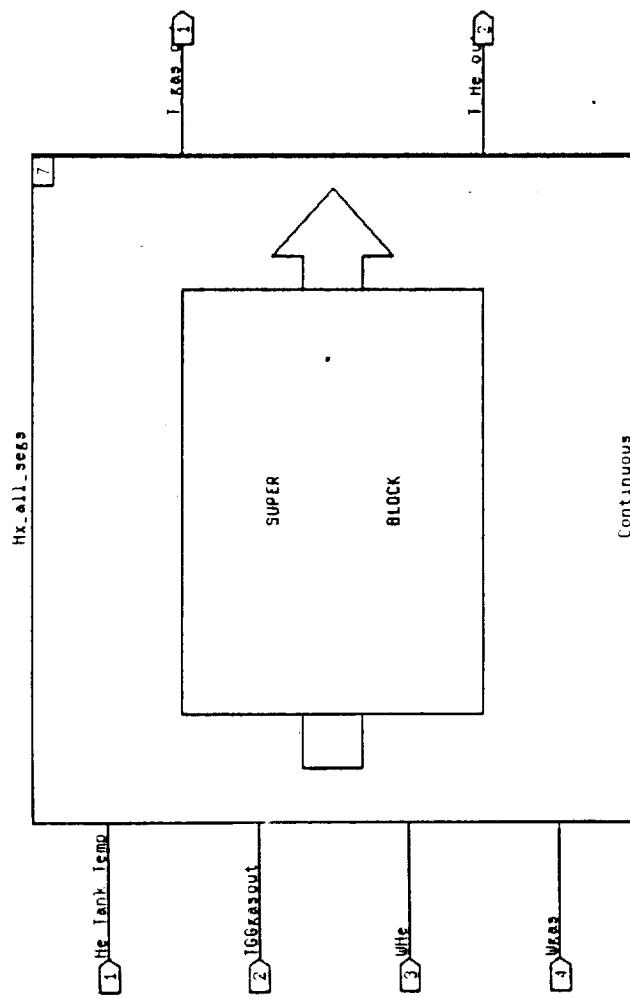
HINTS

Continuous Super-Block
welse
Ext. Inputs Ext. Outputs



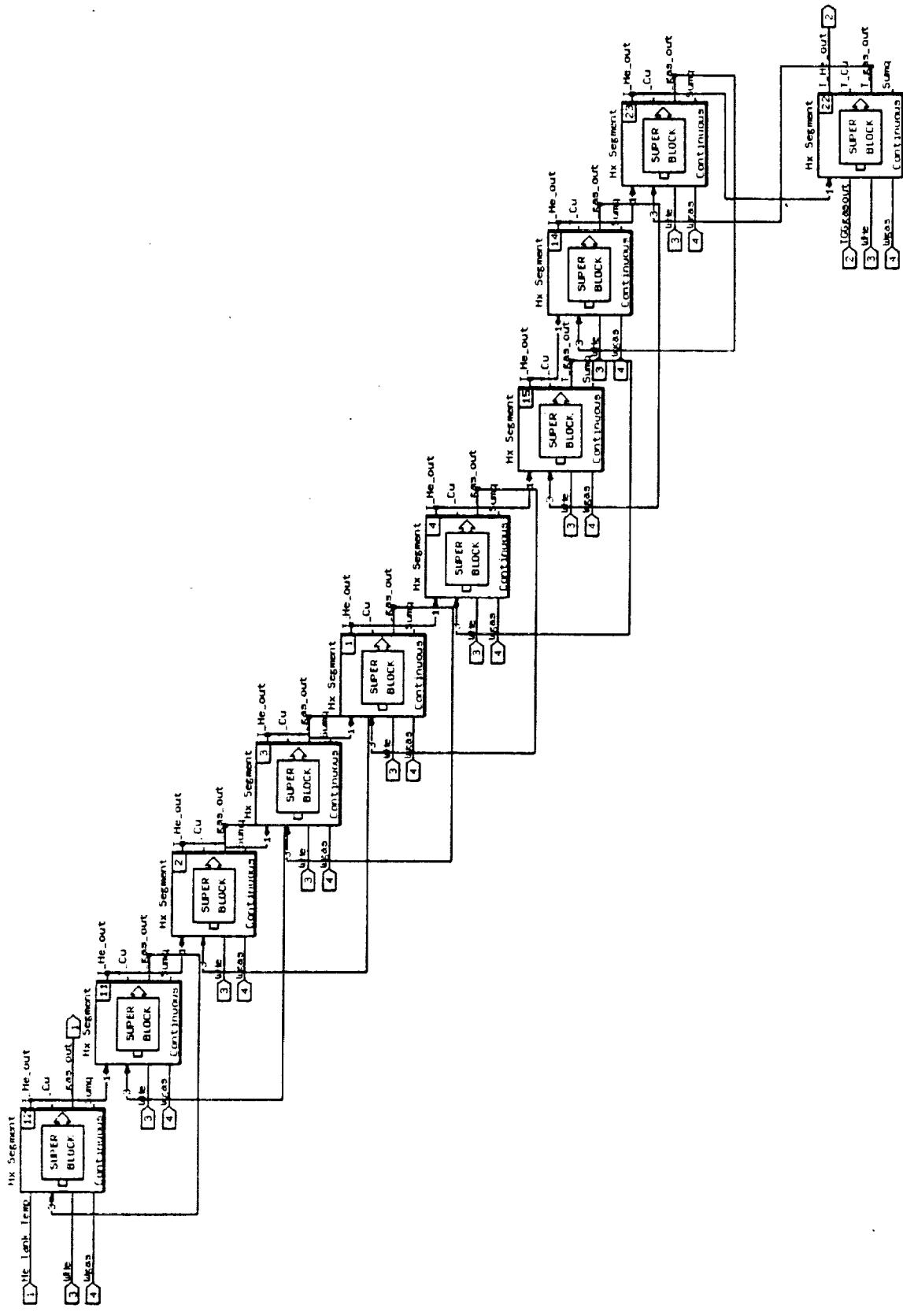
HINTS

Continuous Super-Block
HeatX Ext. Inputs Ext. Outputs
 4 2



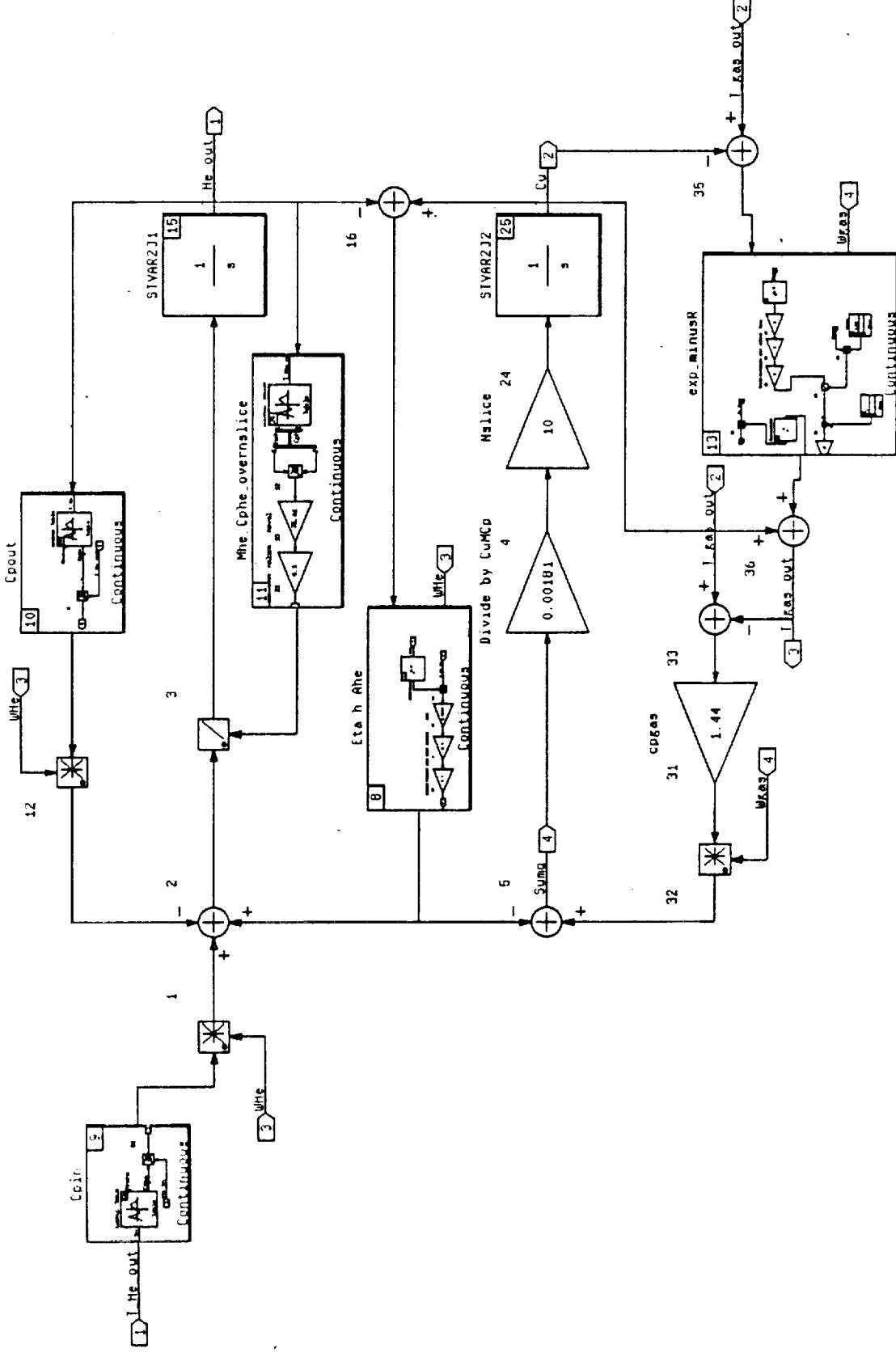
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
Hx_all_segs 4 2



HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
 Hx Segment 4 4



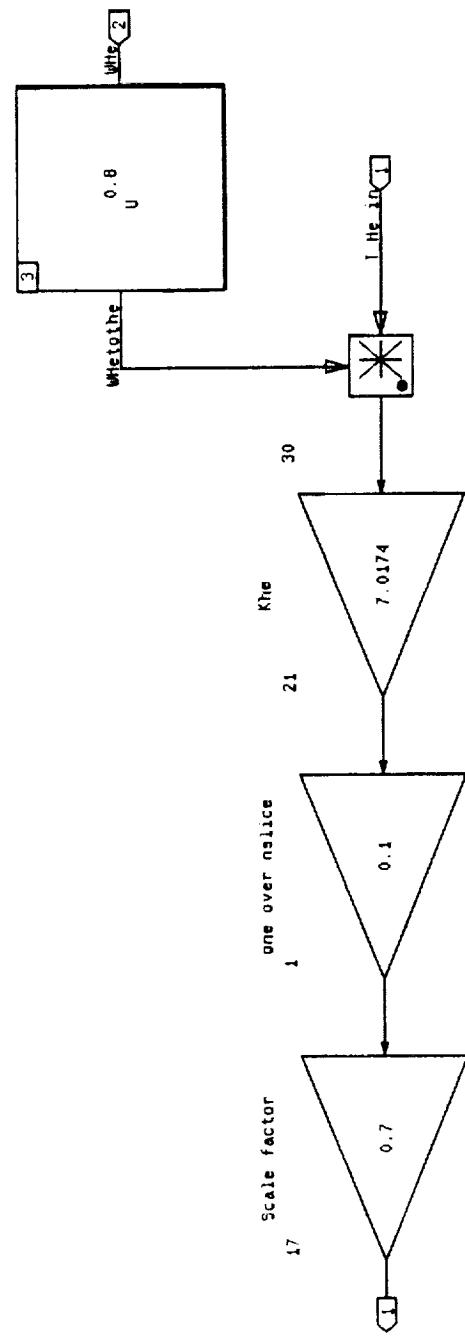
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HINTS

Continuous Super-Block
Eta h Ahe

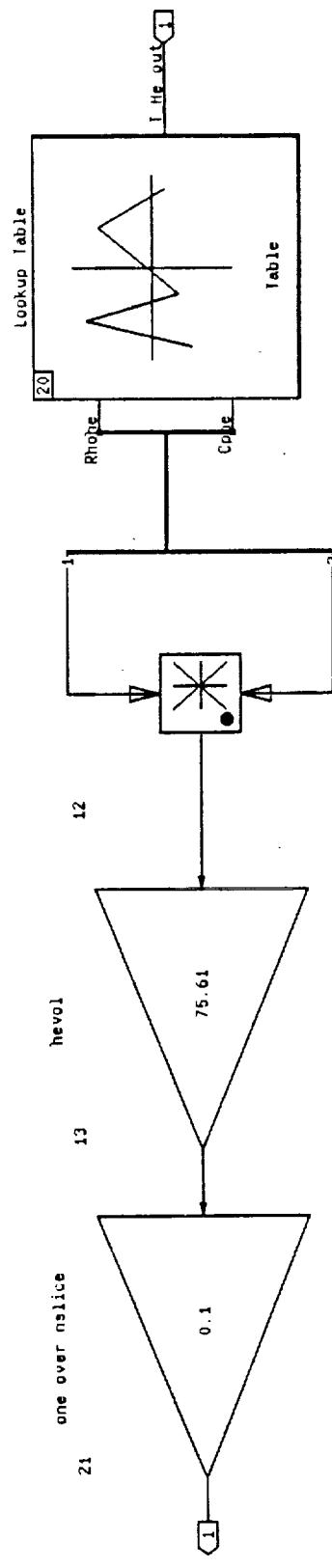
Ext. Inputs 2

Ext. Outputs 1



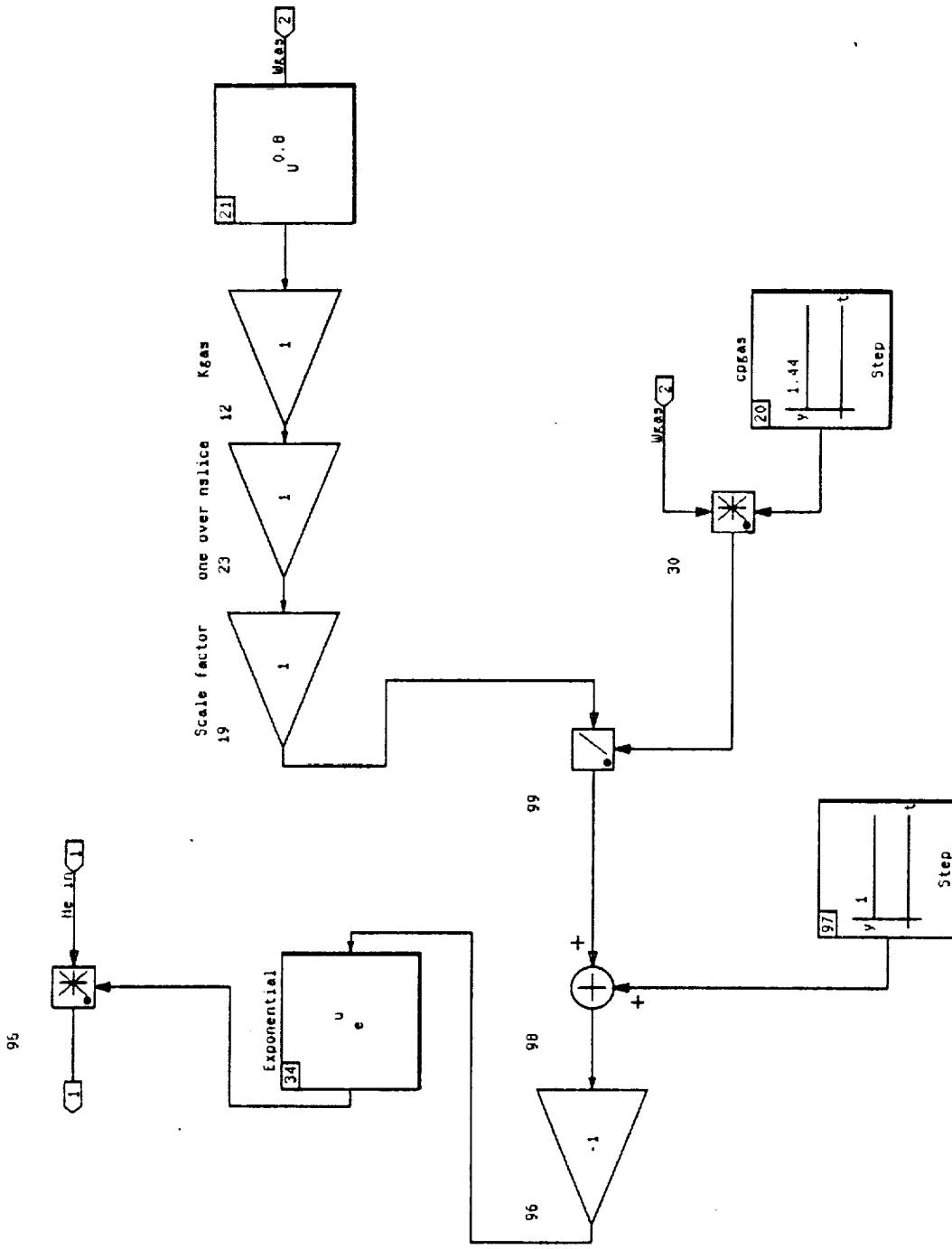
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
Mhe_Cphc_overSlice 1 1



HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
exp_minusR 2 1

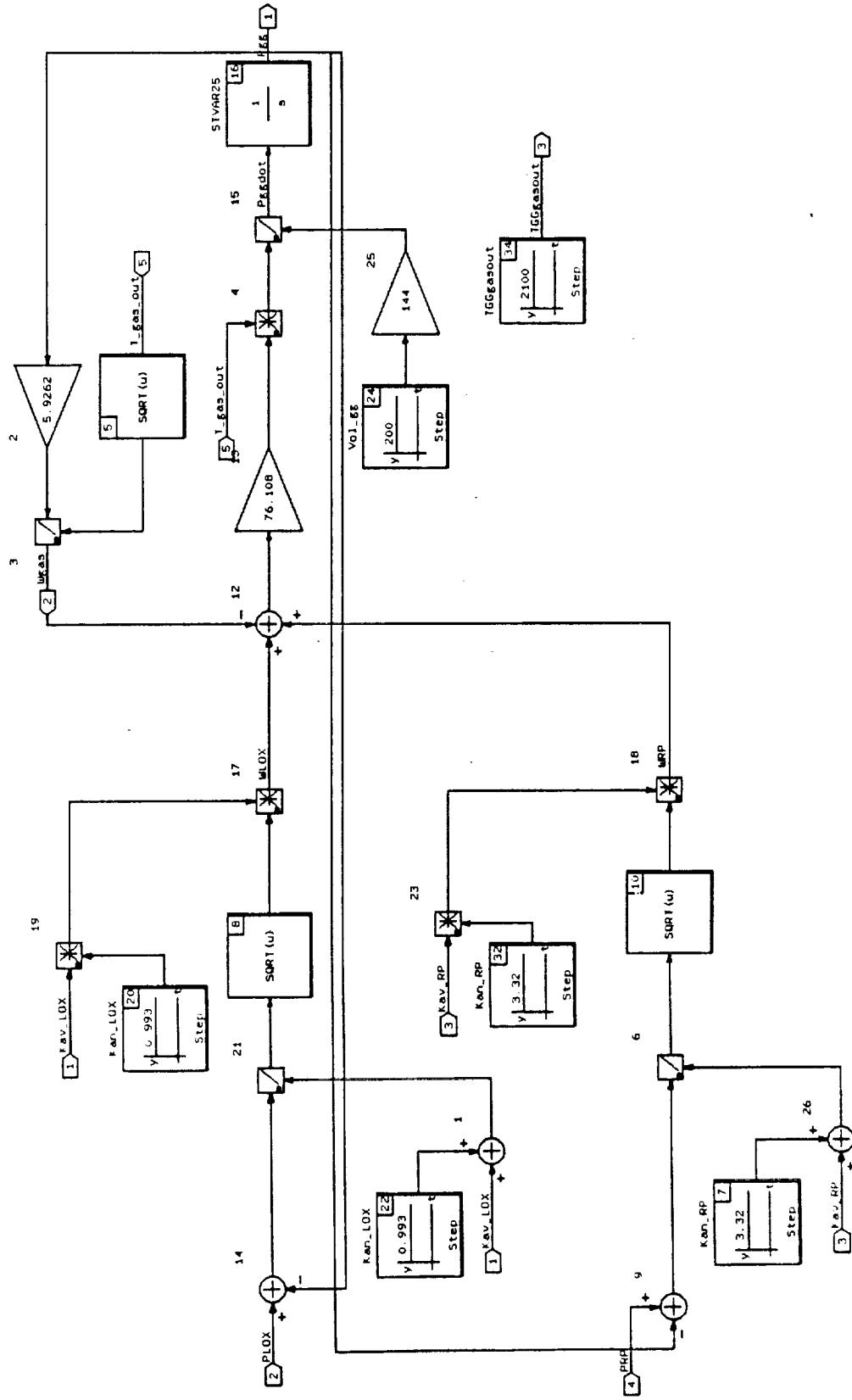


HINTS

Continuous Super-Block
Gas Generator

Ext. Inputs Ext. Outputs

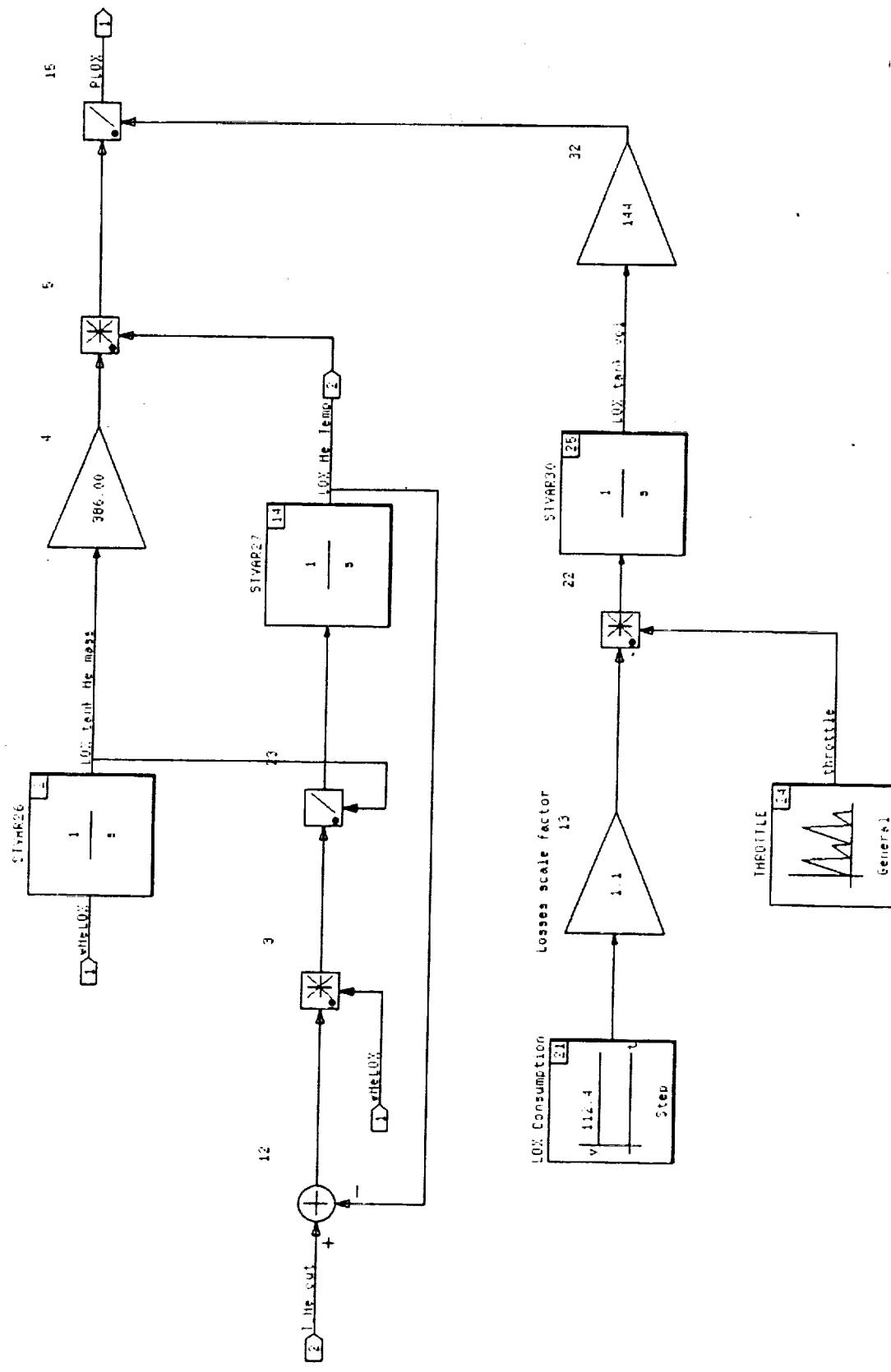
5 3



HINTS

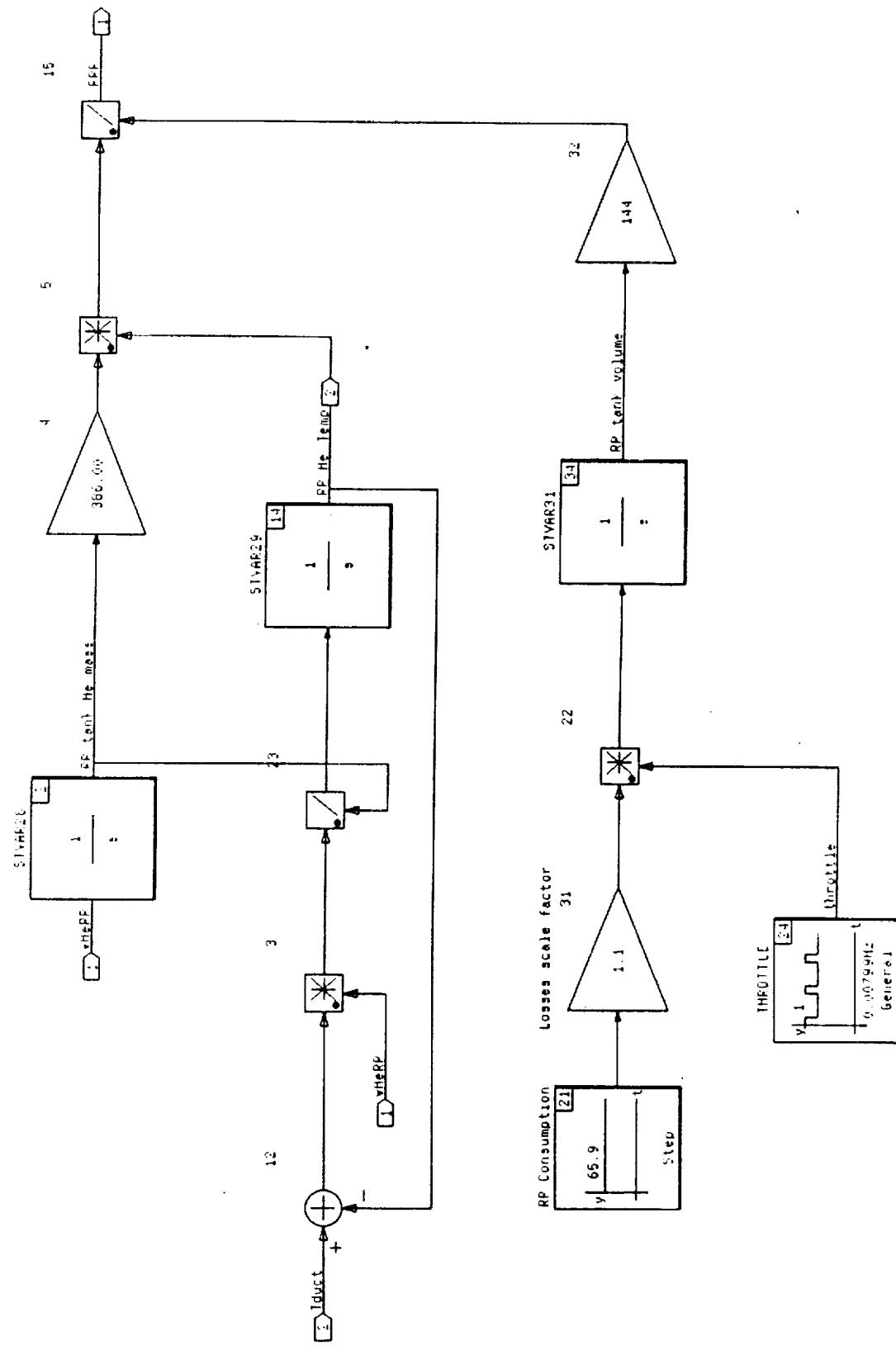
Continuous Super-Block
LOX Tank

Ext. Inputs Ext. Outputs



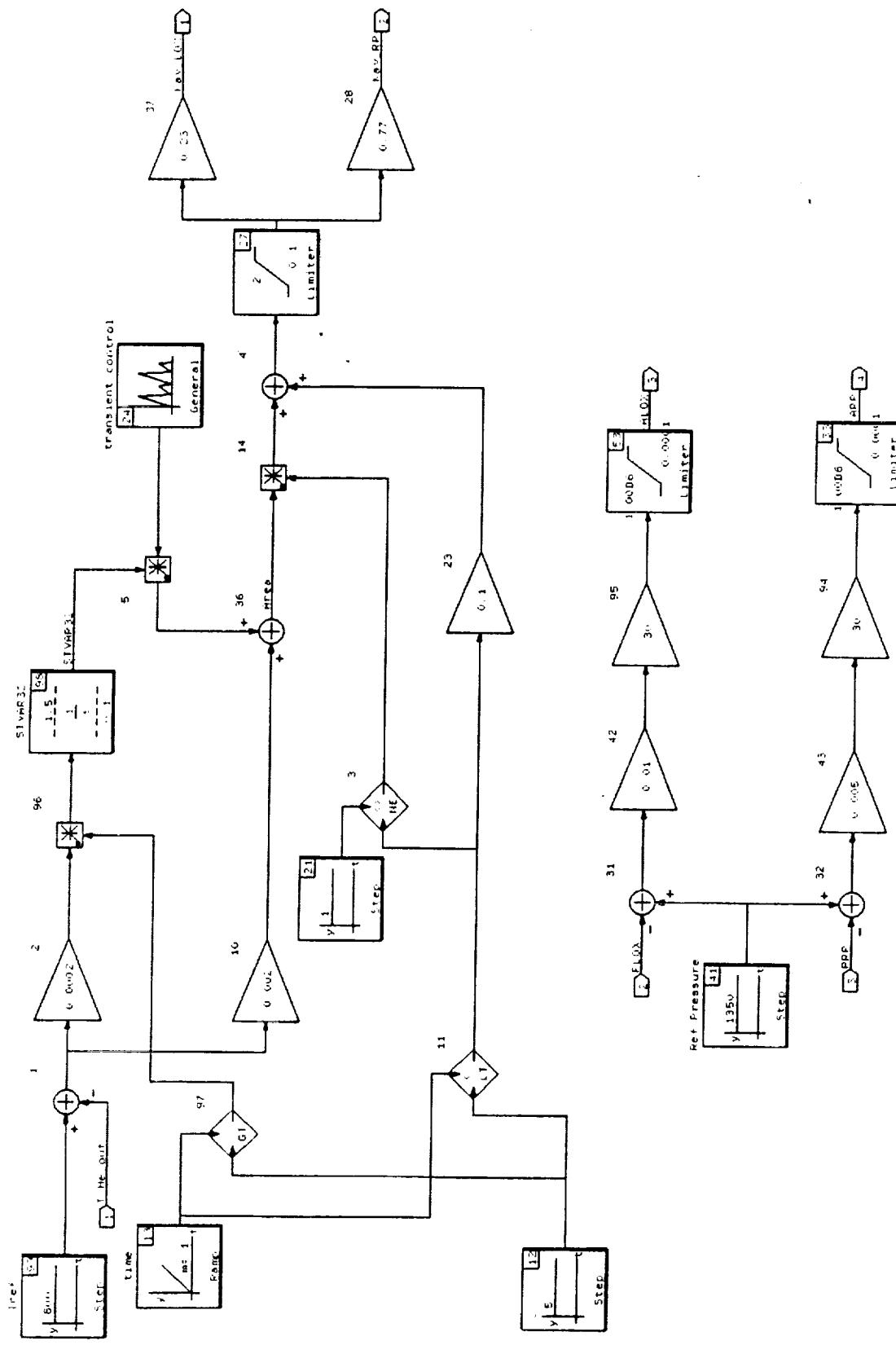
HINTS

Continuous Super-Block
Ext. Inputs Ext. Outputs
RP Tank 2 2



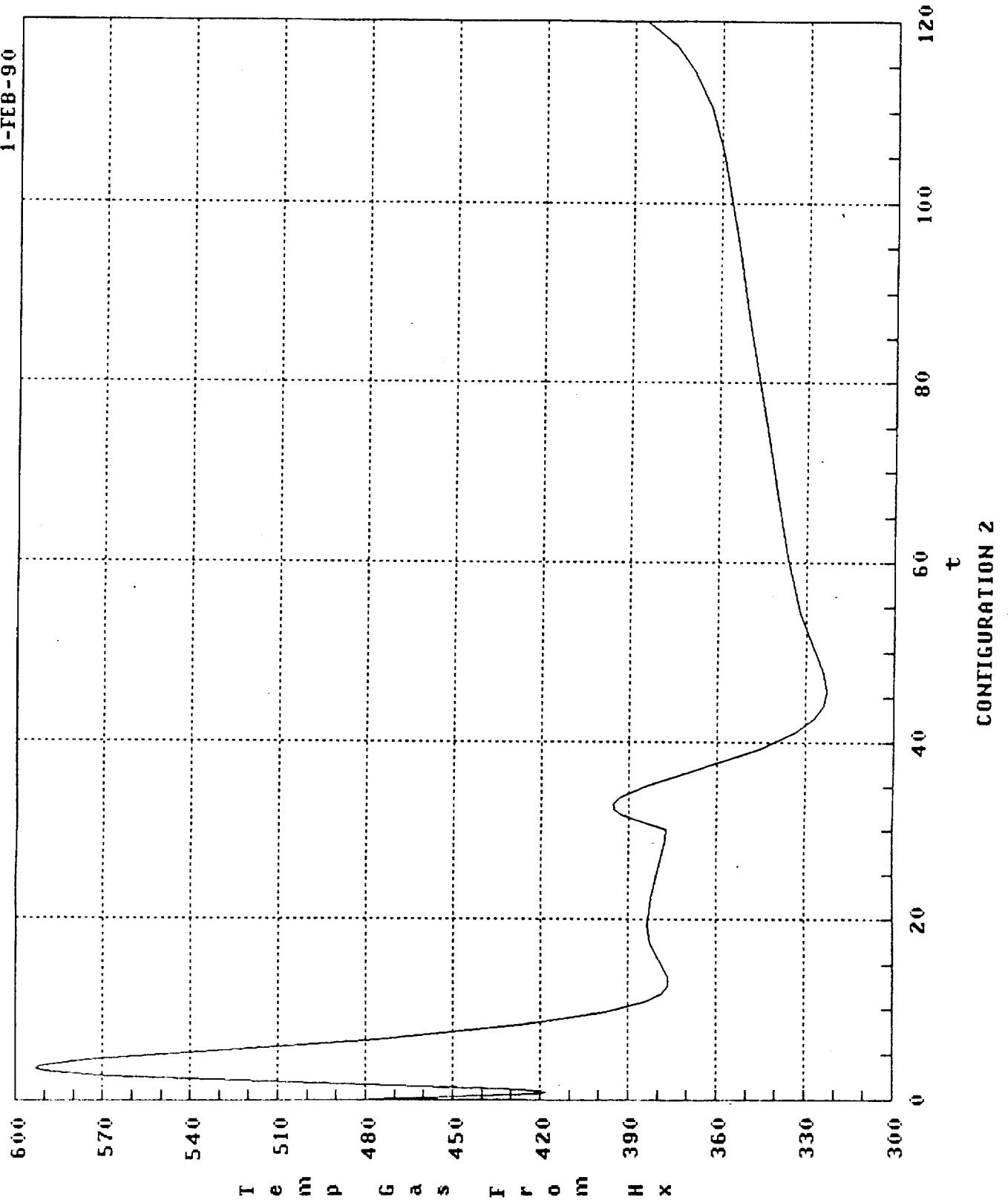
HINTS

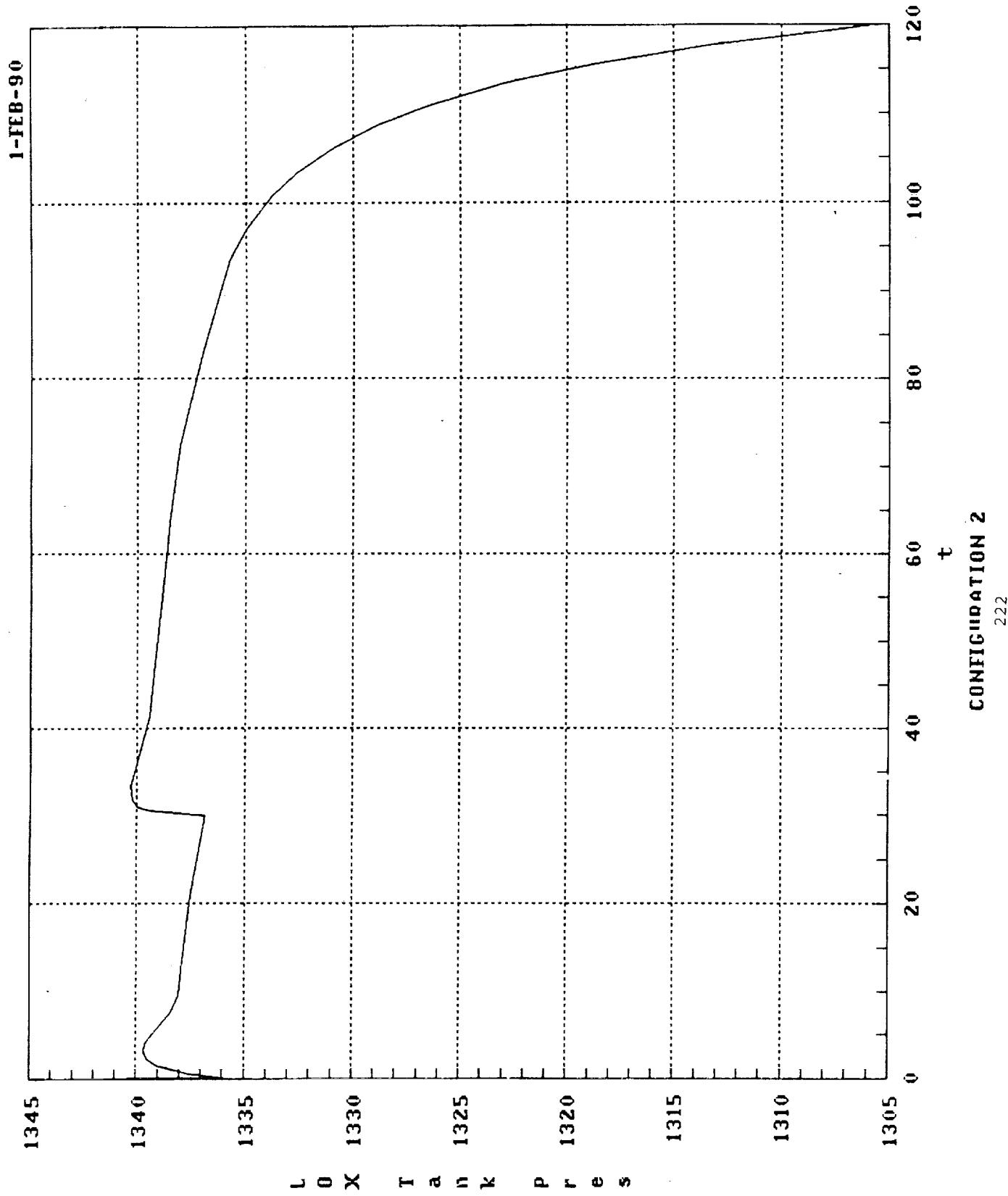
Continuous Super-BLOCK Controller Ext. Inputs Ext. Outputs
 3 4

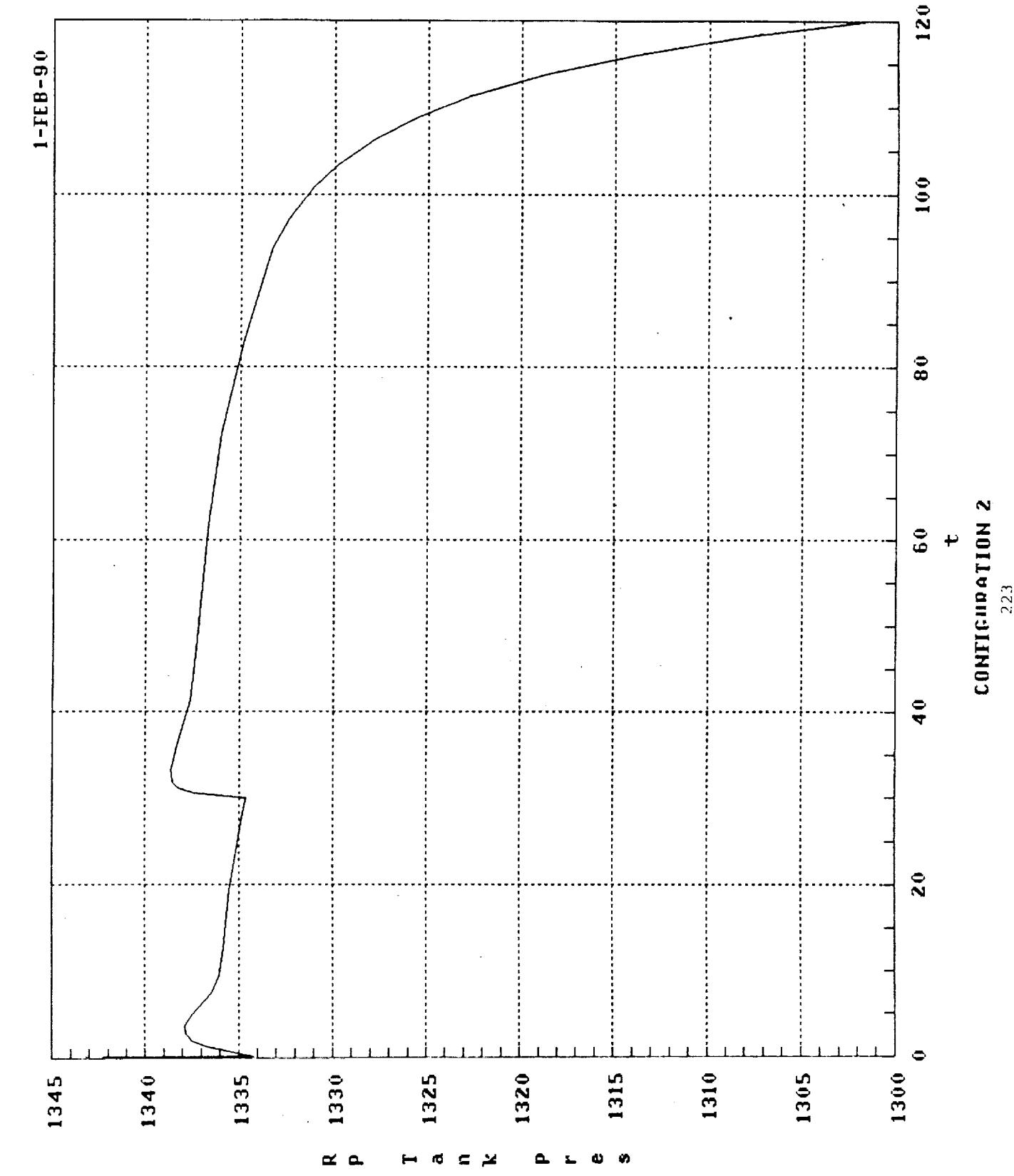


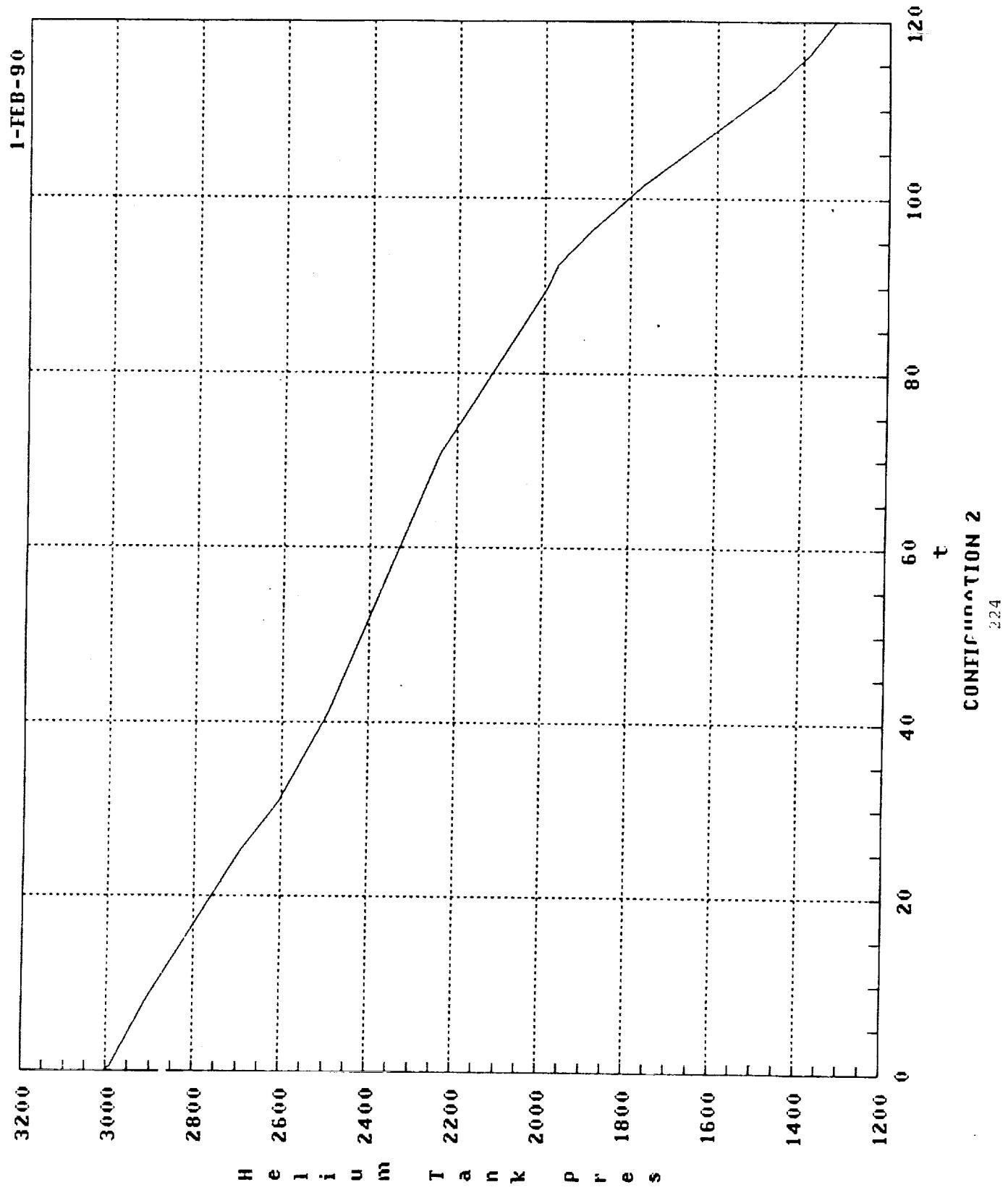
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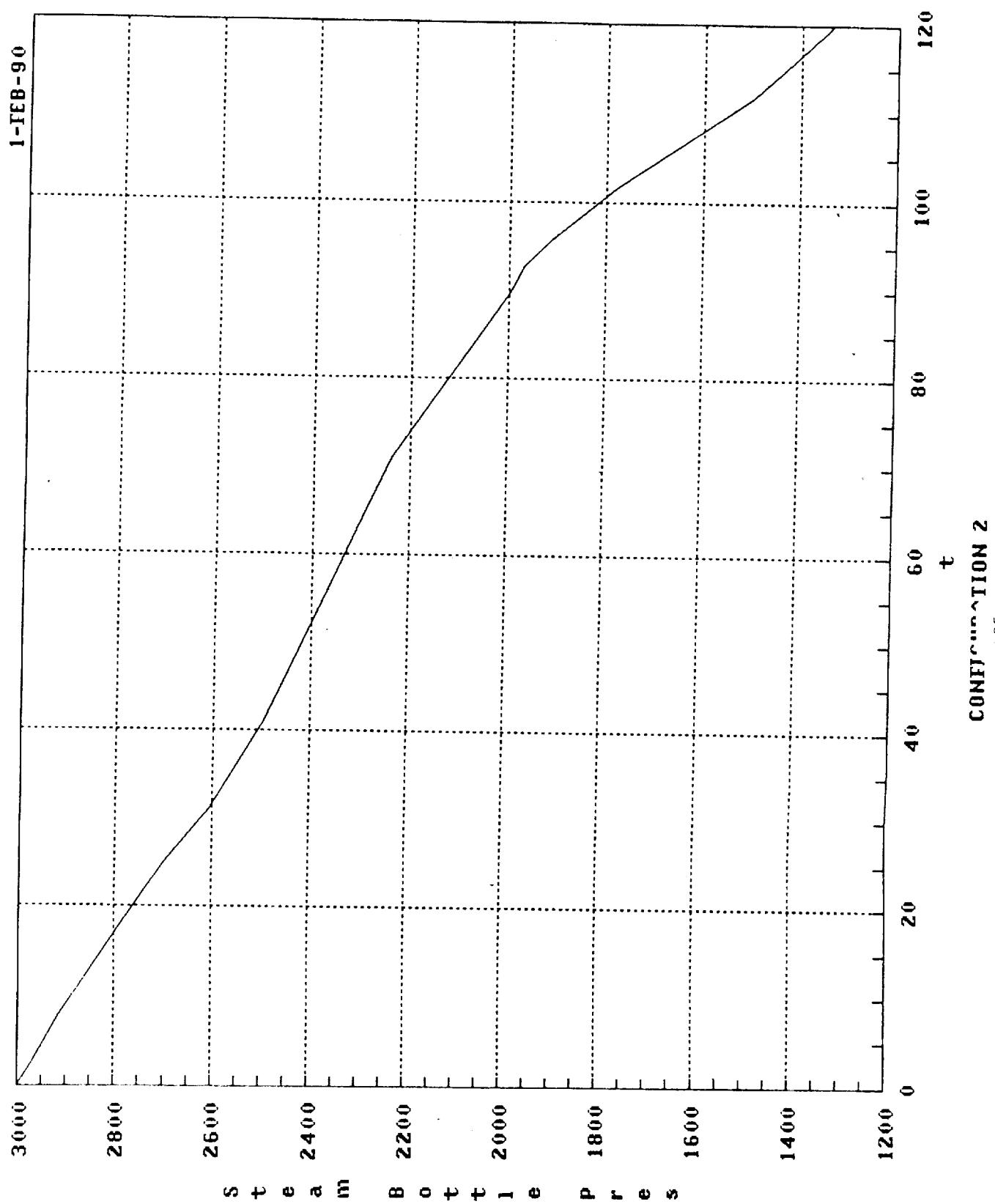
1-FEB-90

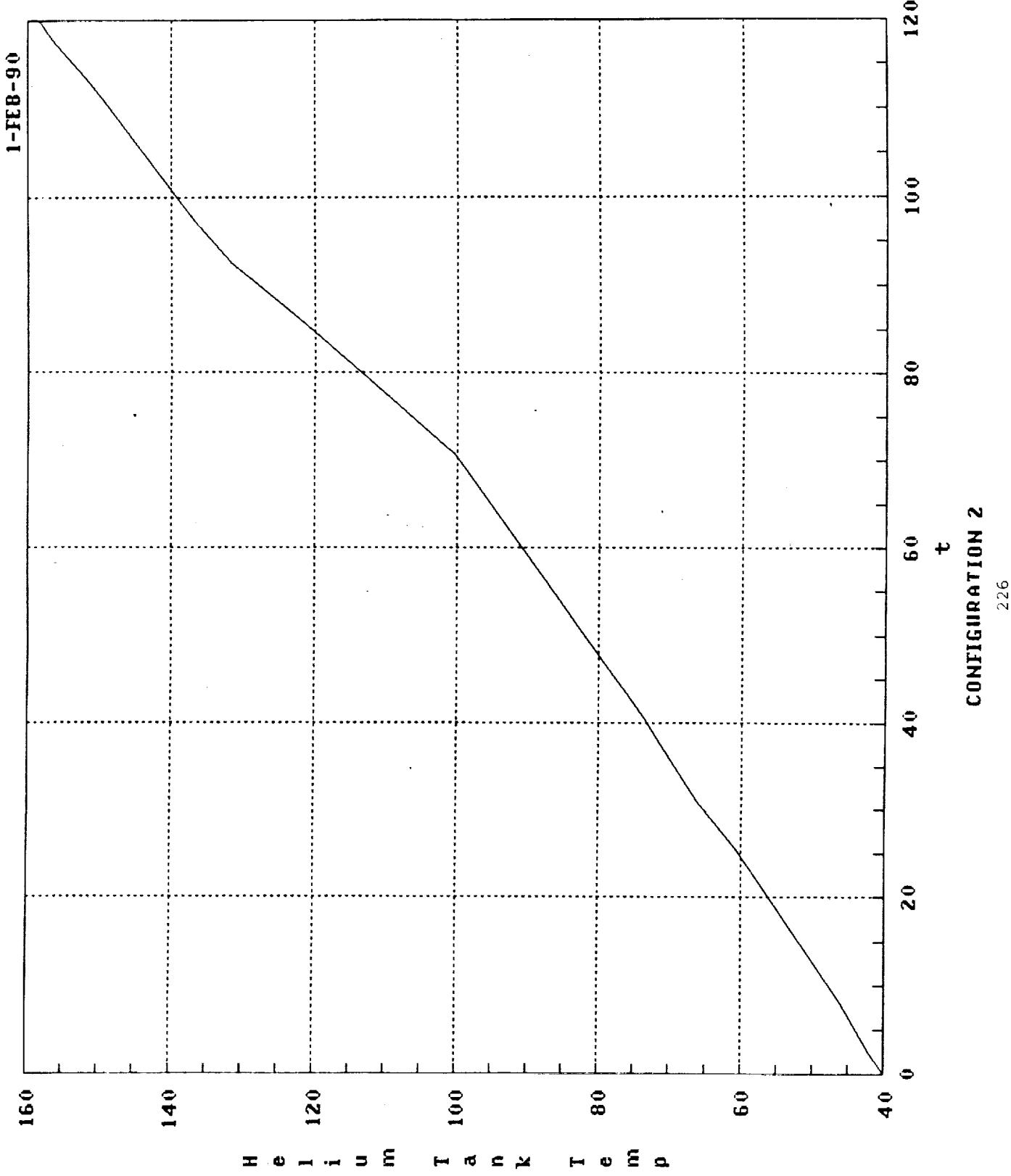


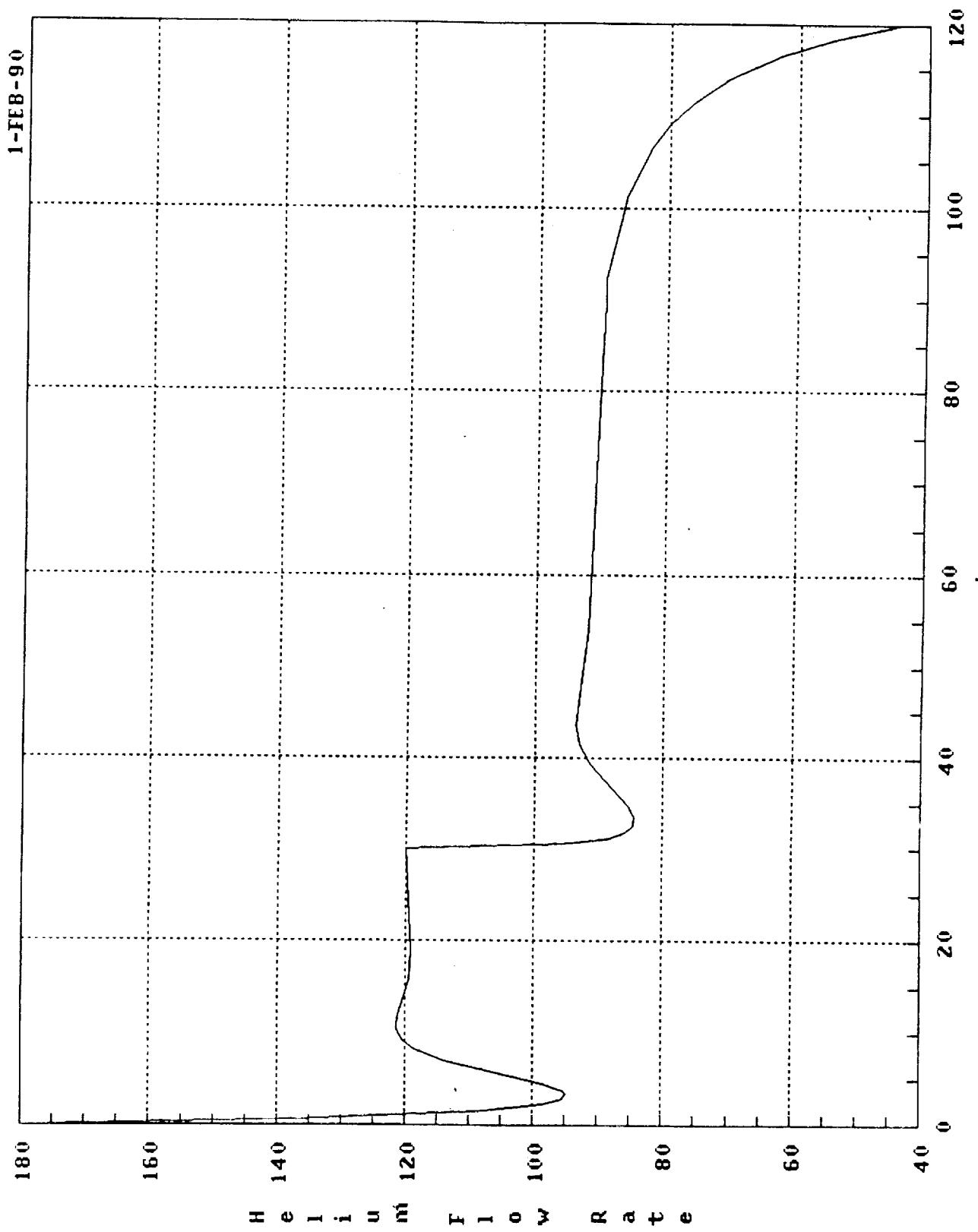






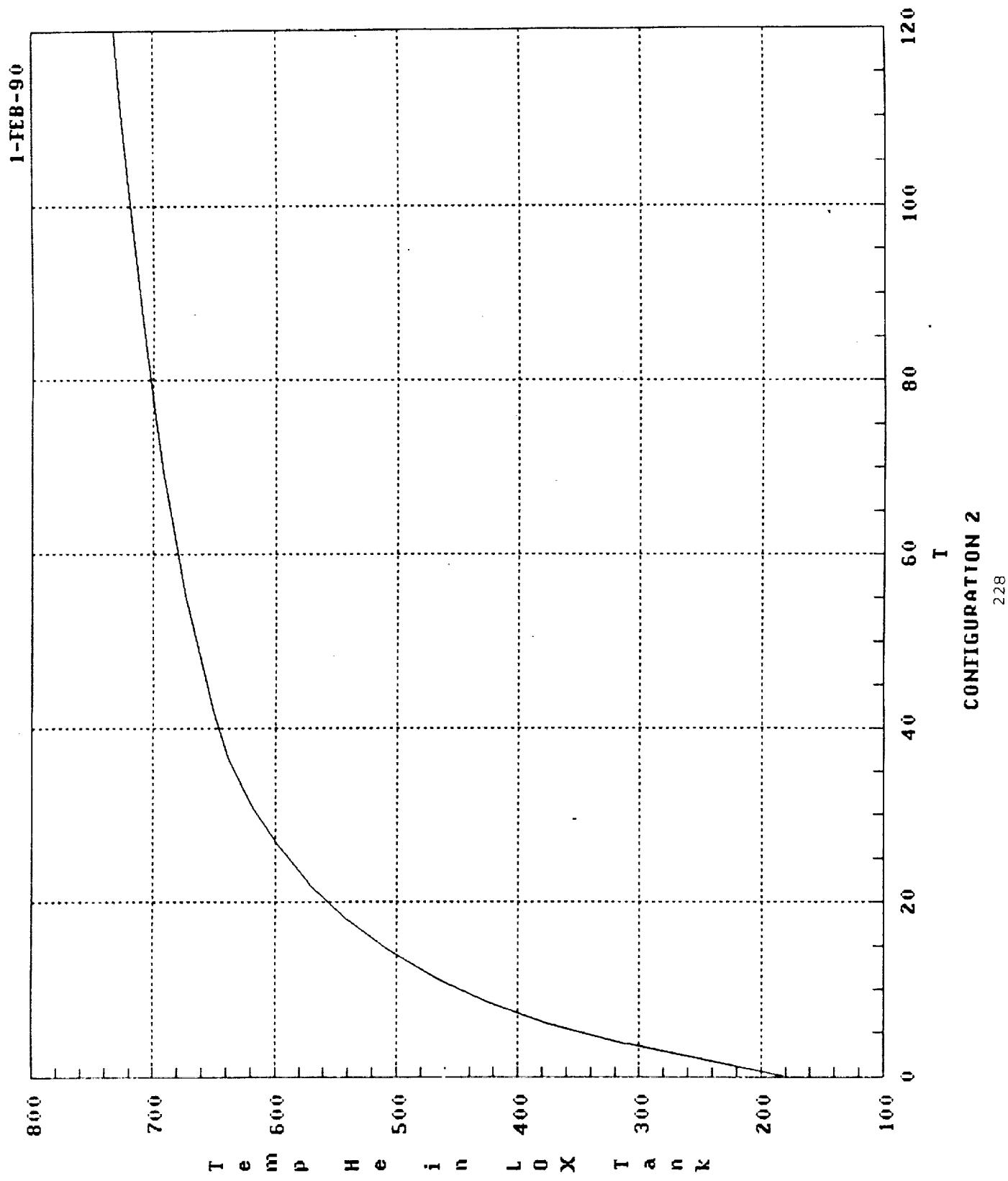






CONFIGURATION 2

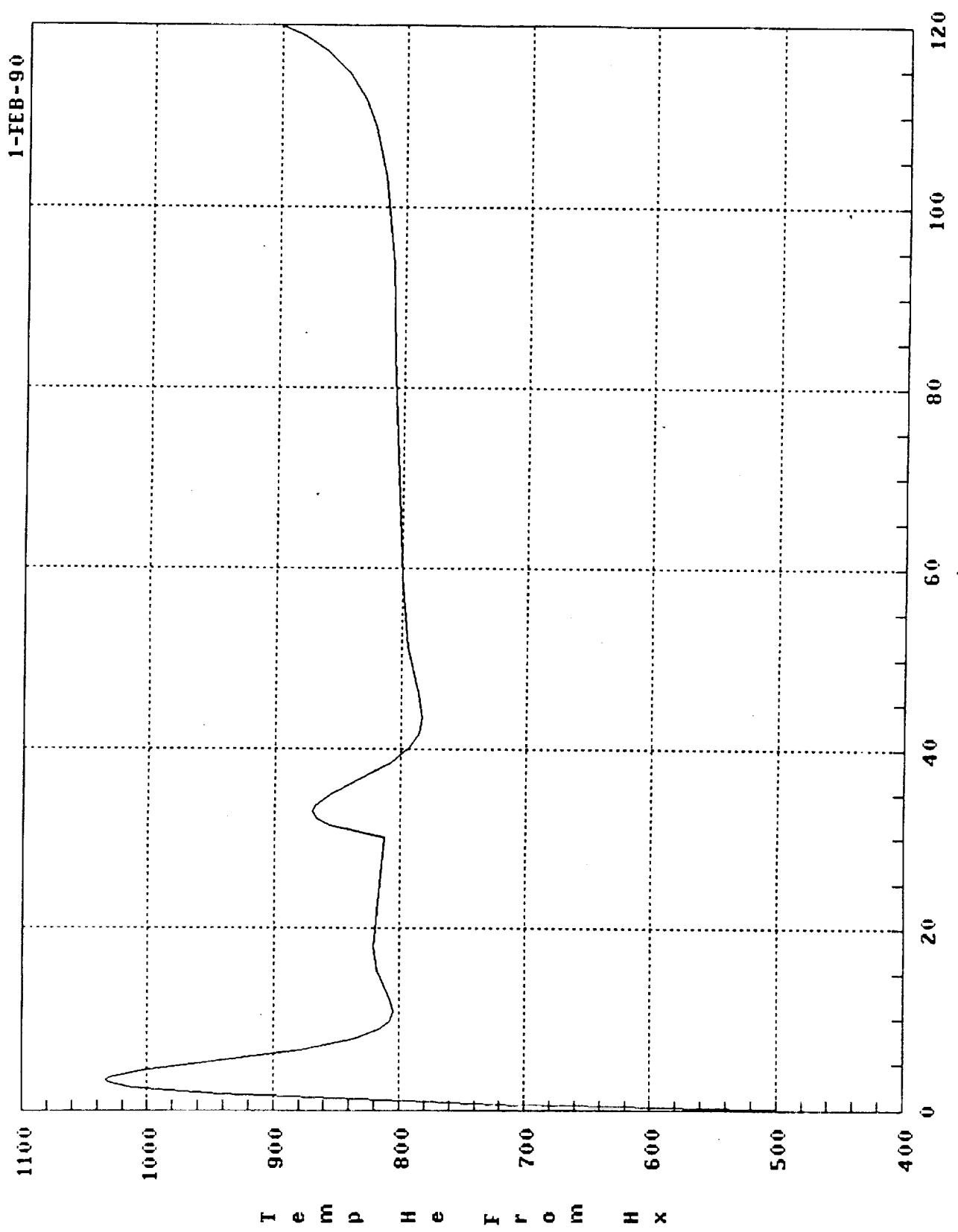
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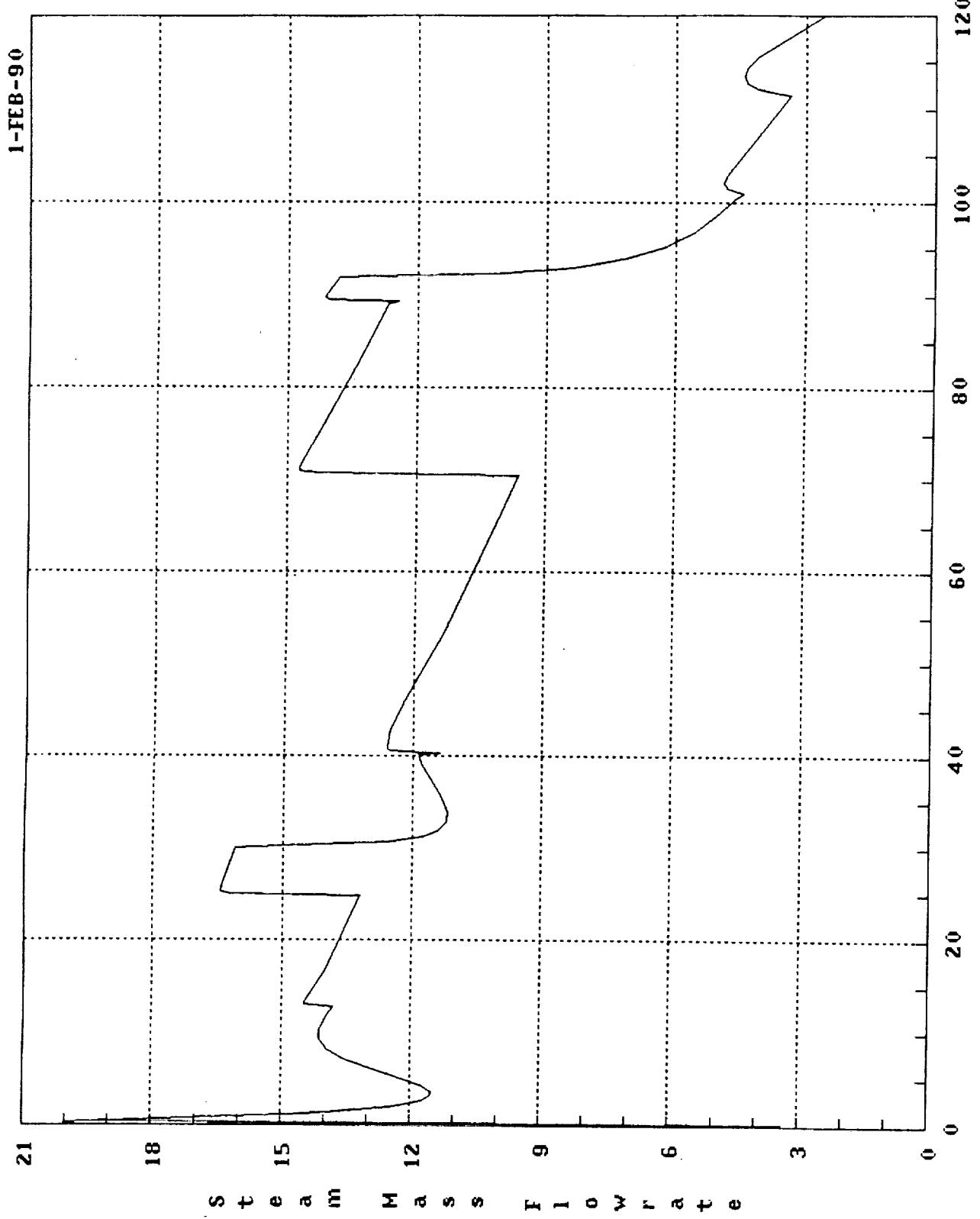


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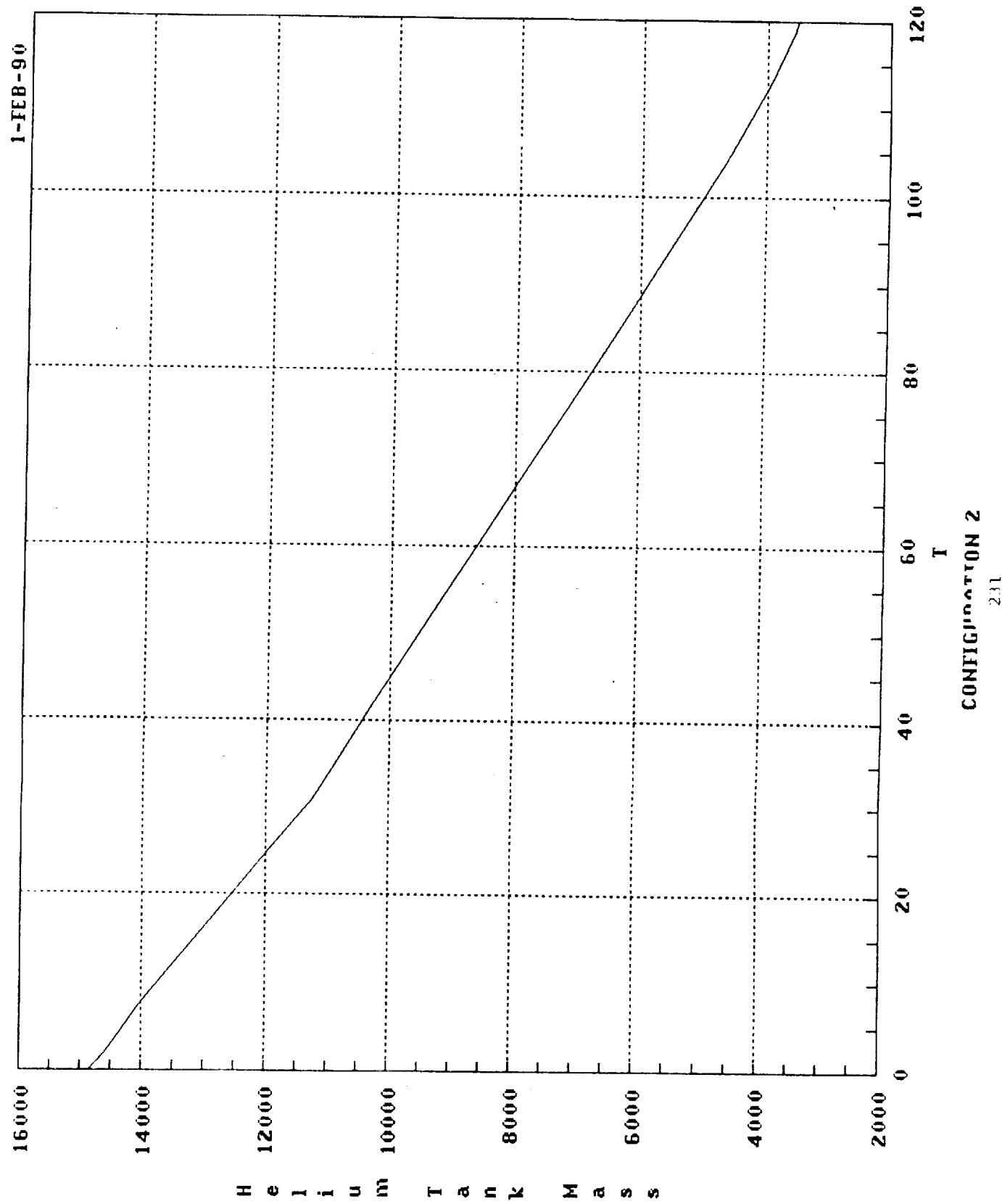
228

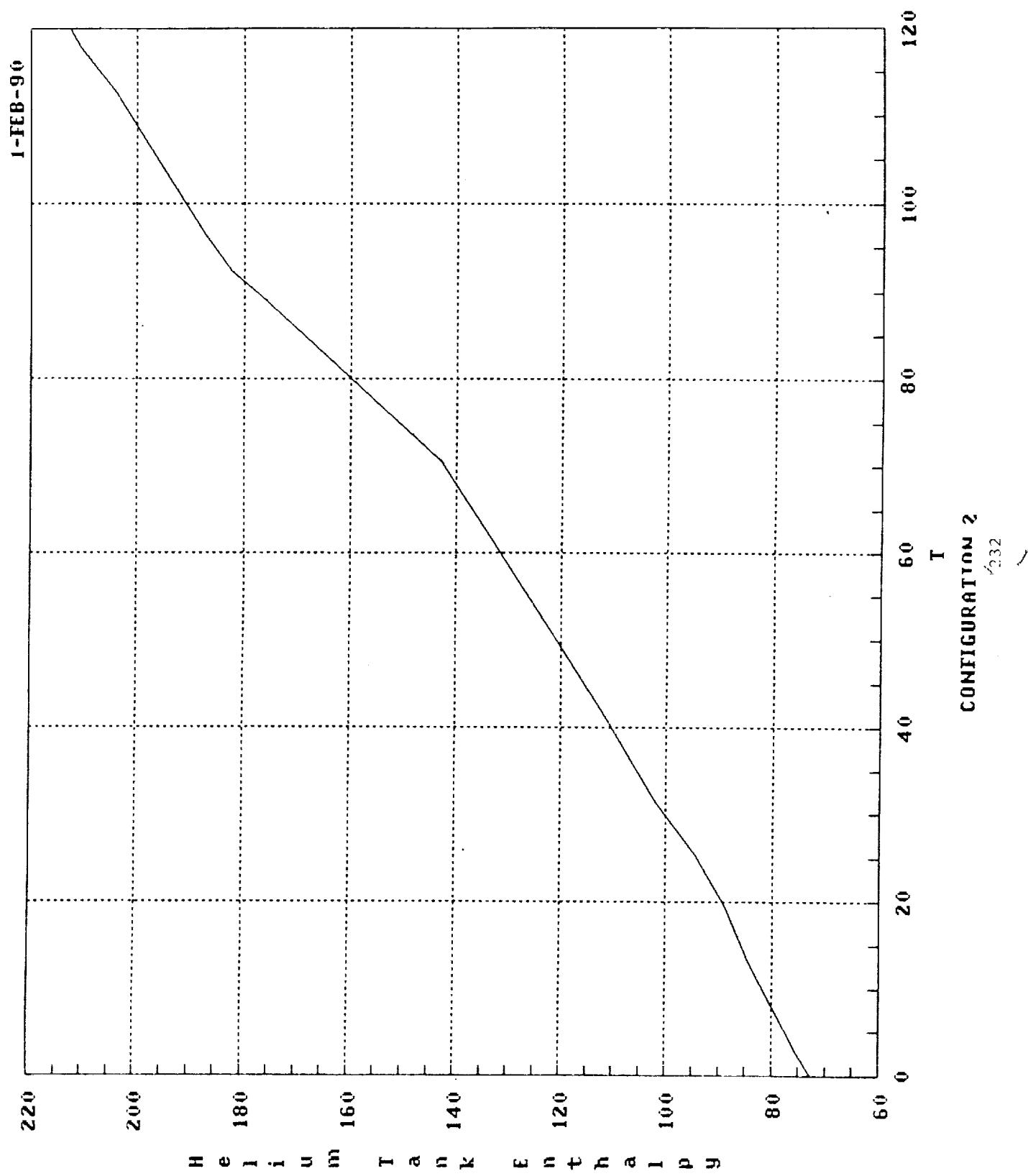
CONFIGURATION 2
229

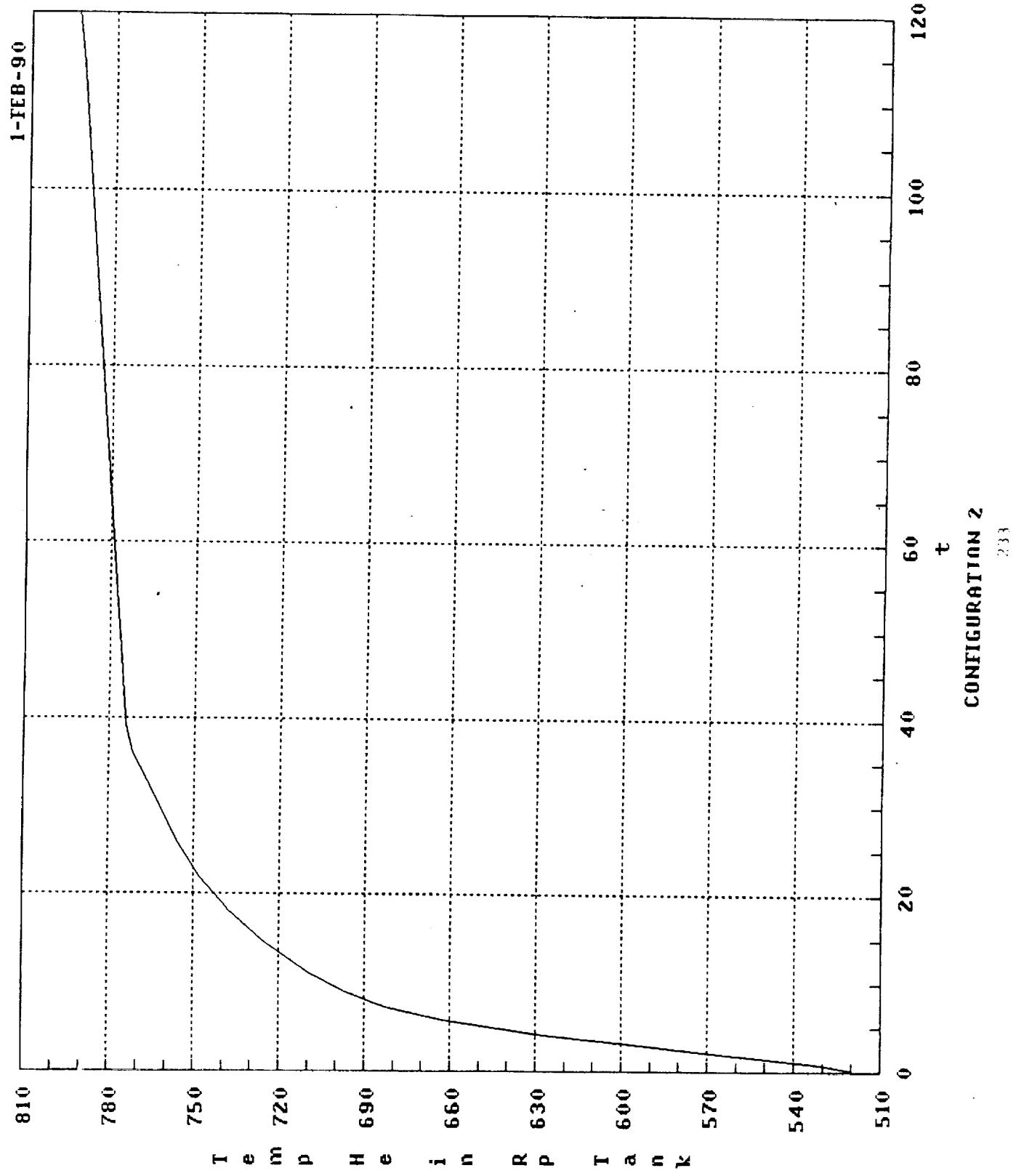


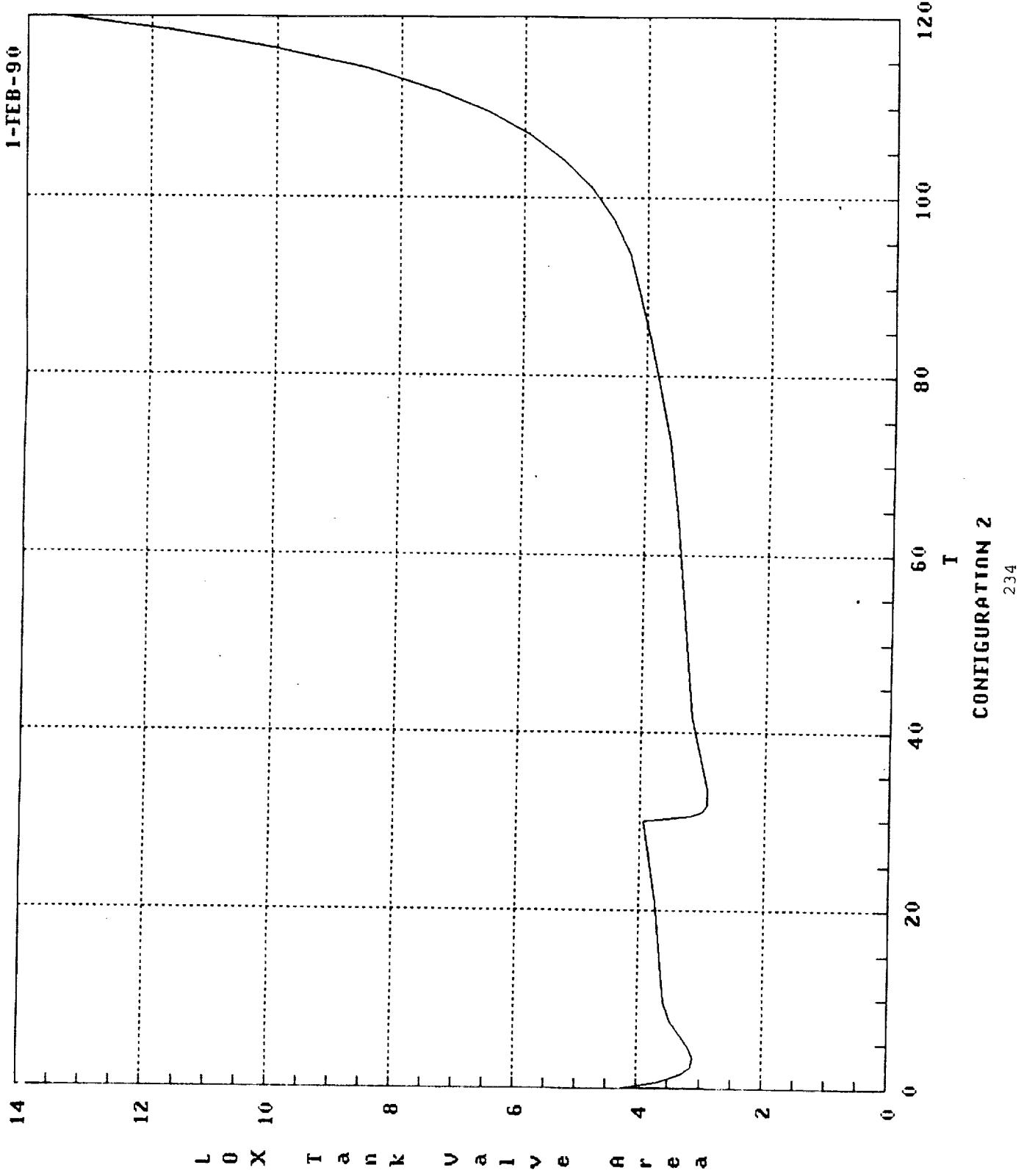


CONFIGURATION 2
230

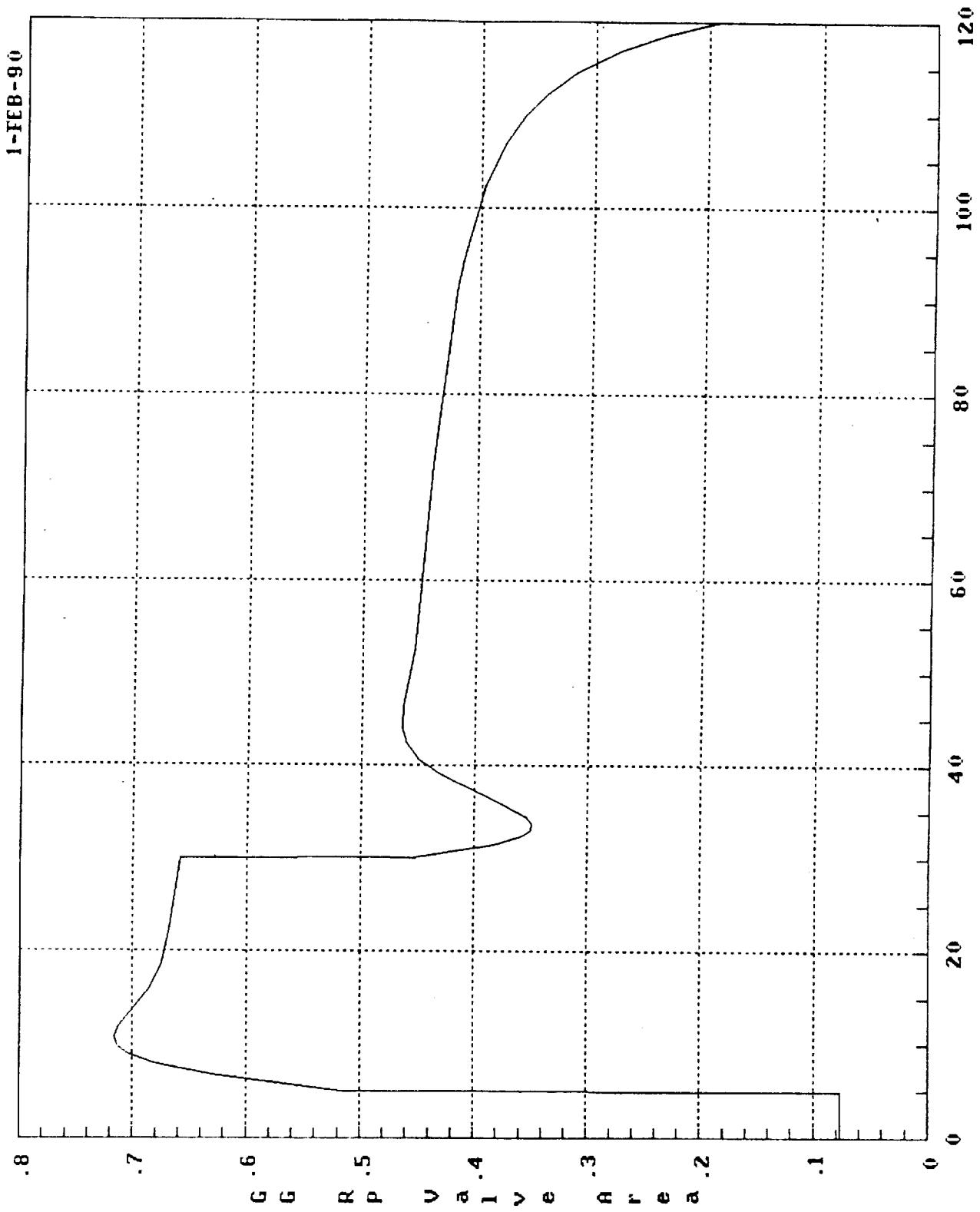




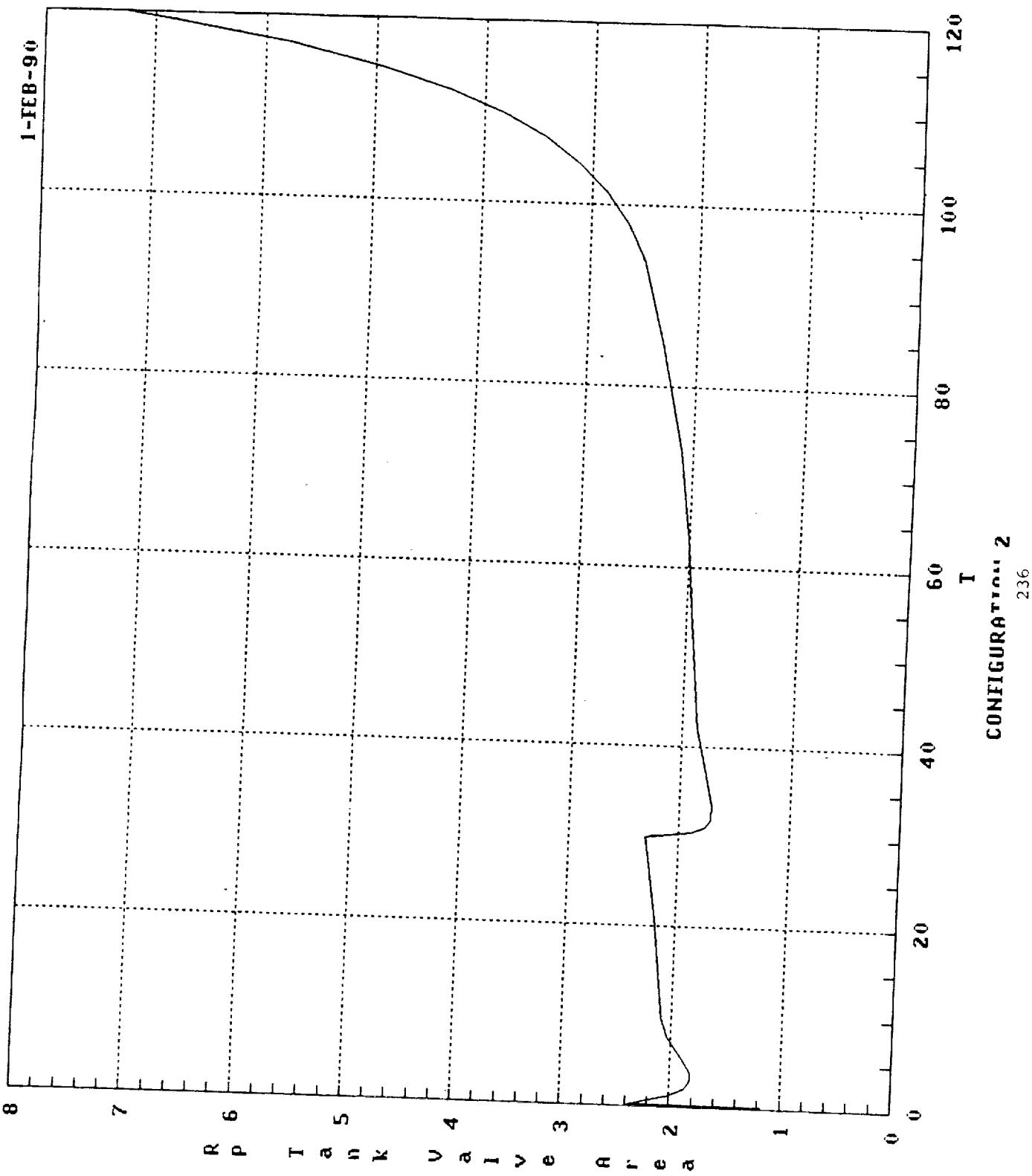




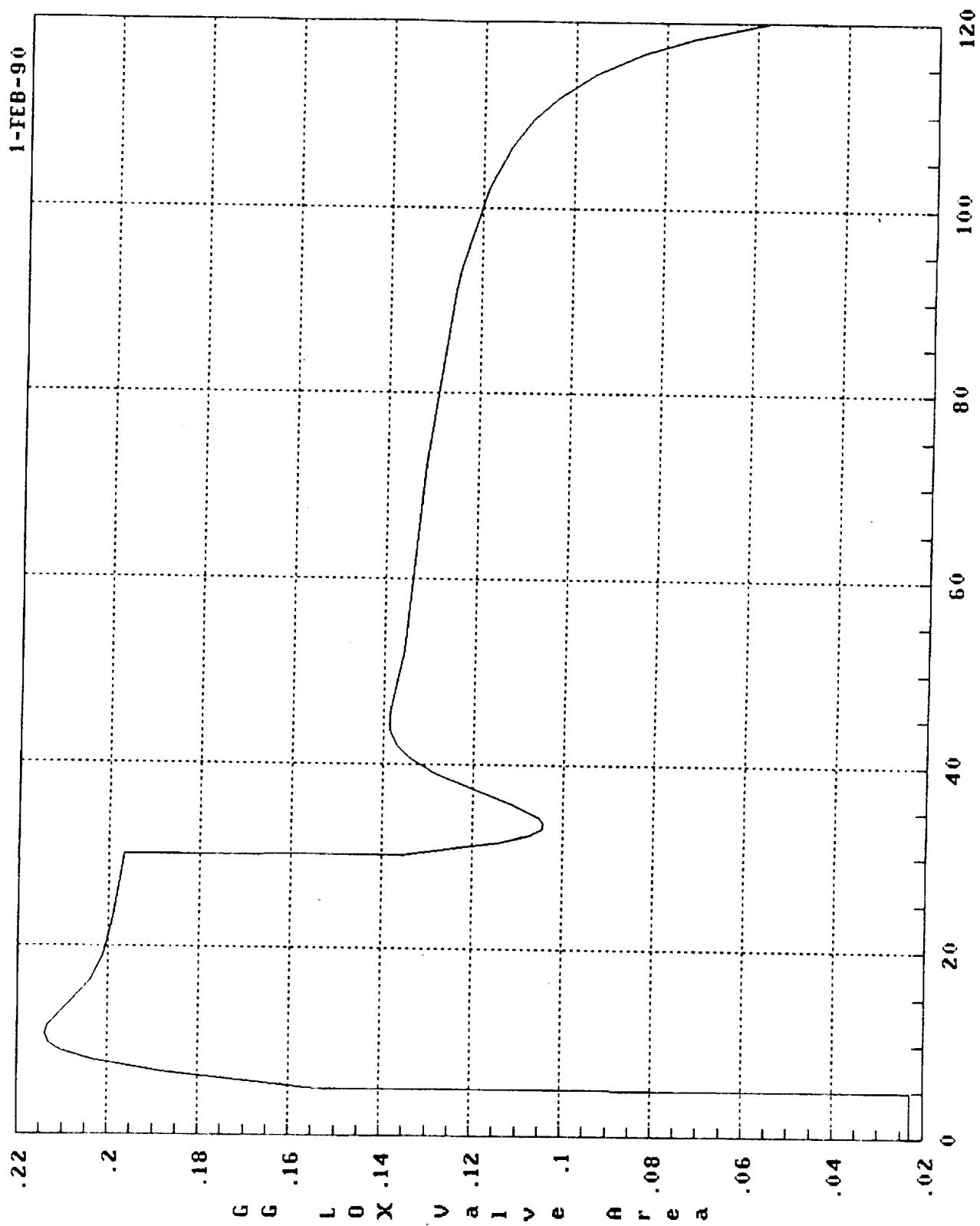
1-FEB-90

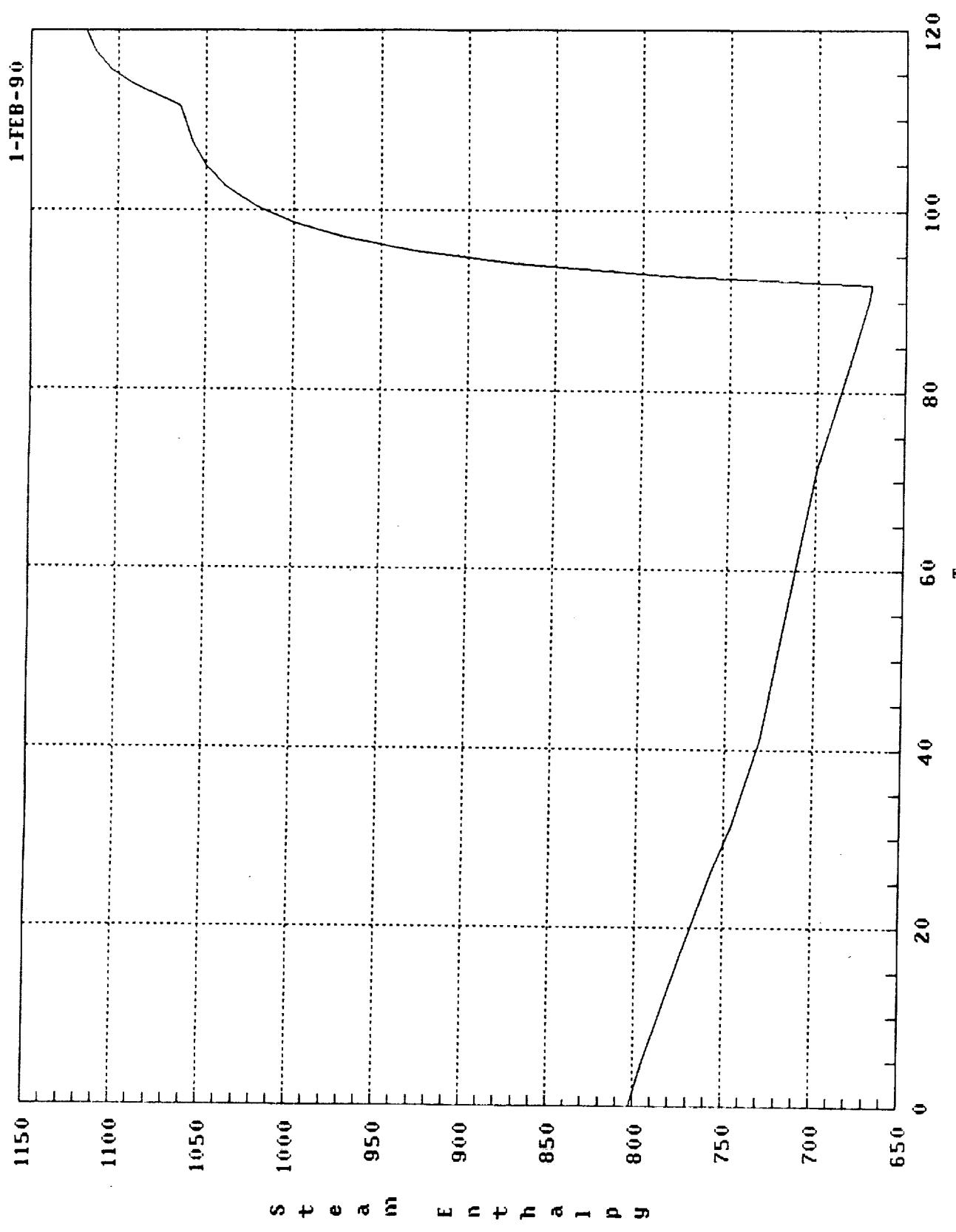


CONFIGURATION 2
2.31



CONFIGURATION 2



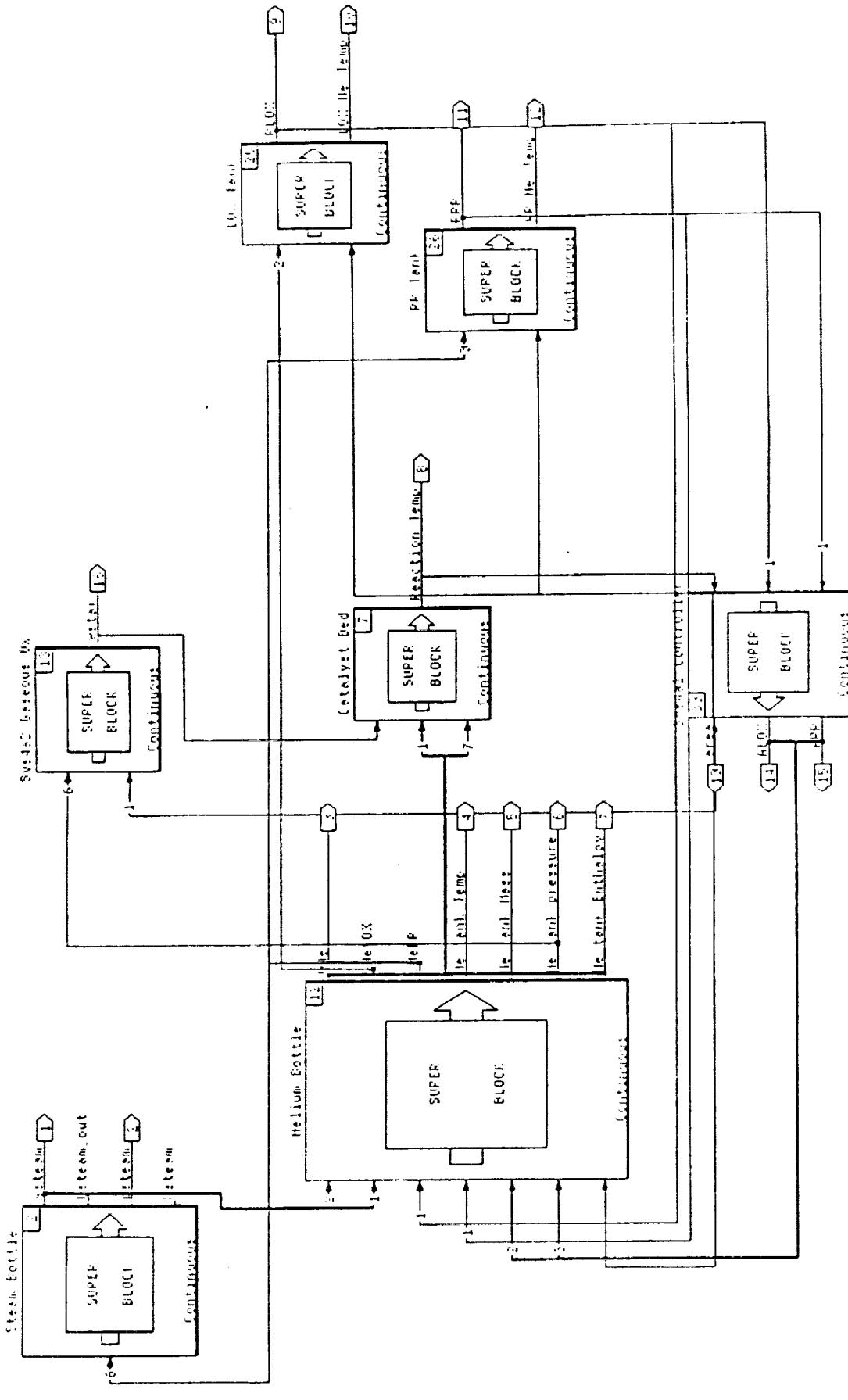


CONFIGURATION 2
238

CONFIGURATION 4a2
CATALYST ALTERNATE STEAM

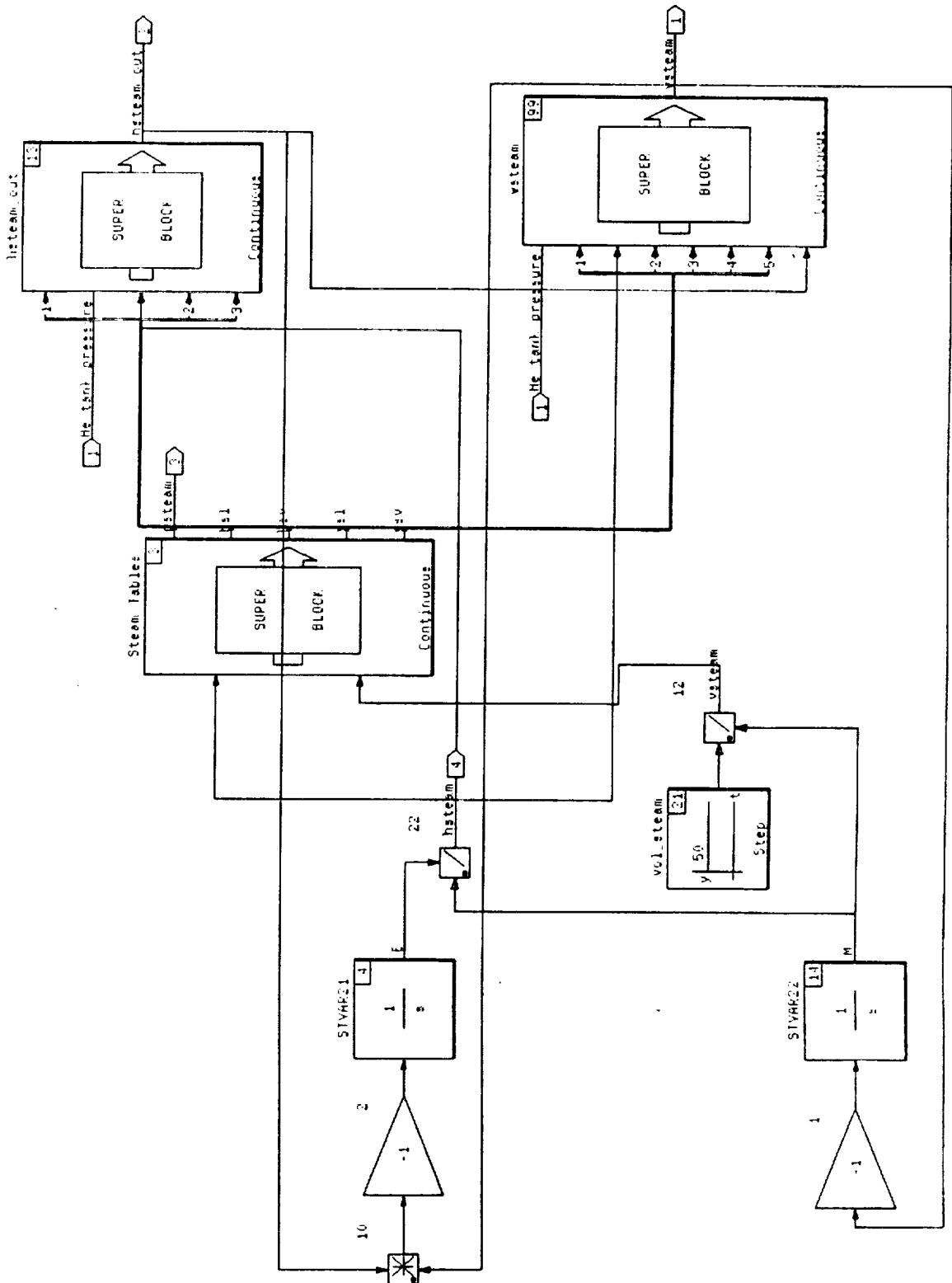
MATRIX X BLOCK DIAGRAMS
MATRIX X PLOTS

Configuration SUPER-BLOCK Ext. Inputs Ext. Outputs J₅



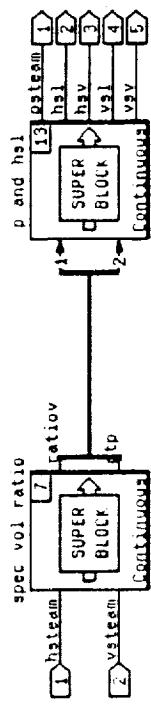
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
Steam Bottle 1 4



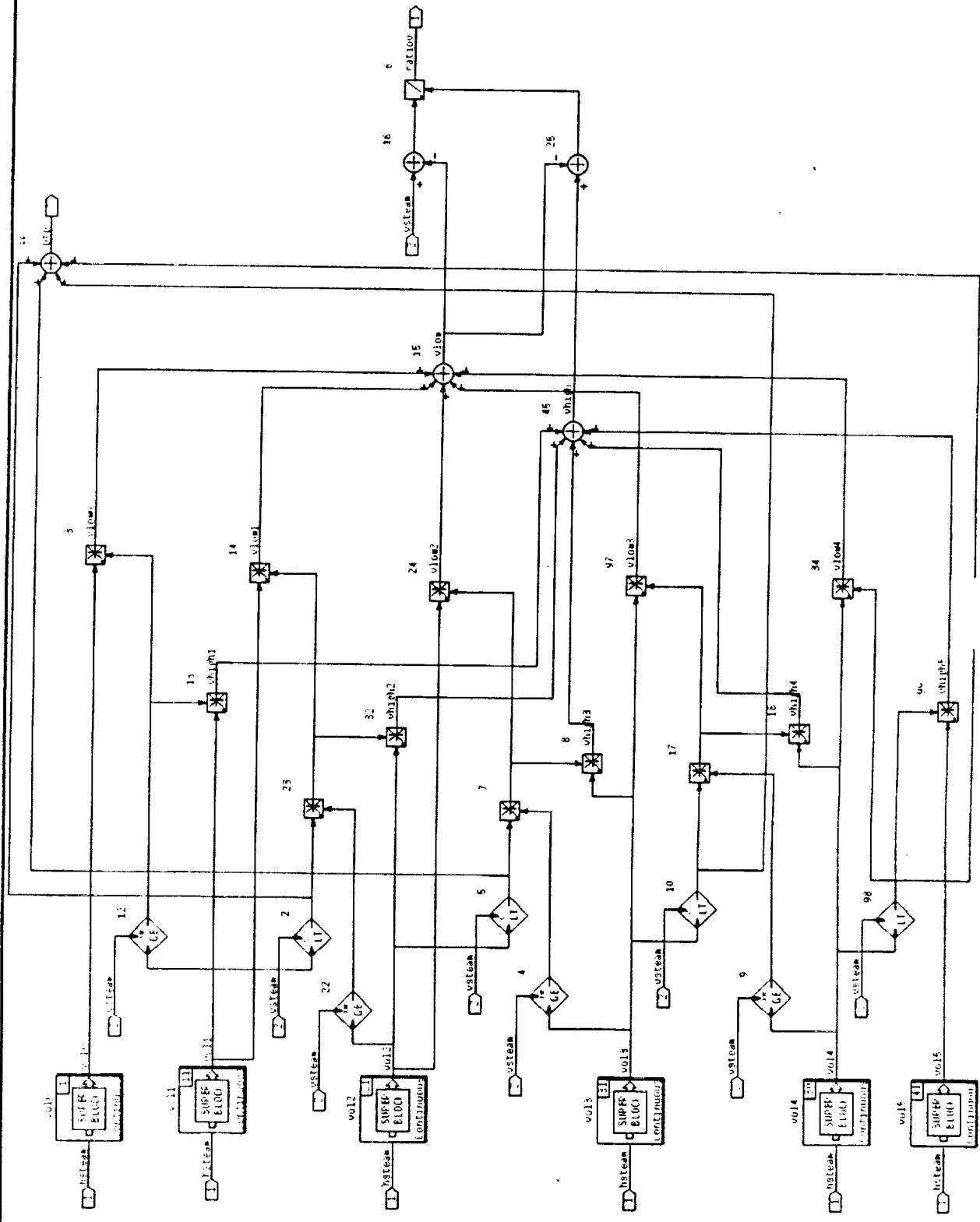
HINTS

Continuous Stream Tables Super-Block Ext. Inputs Ext. Outputs
5 2 2 5



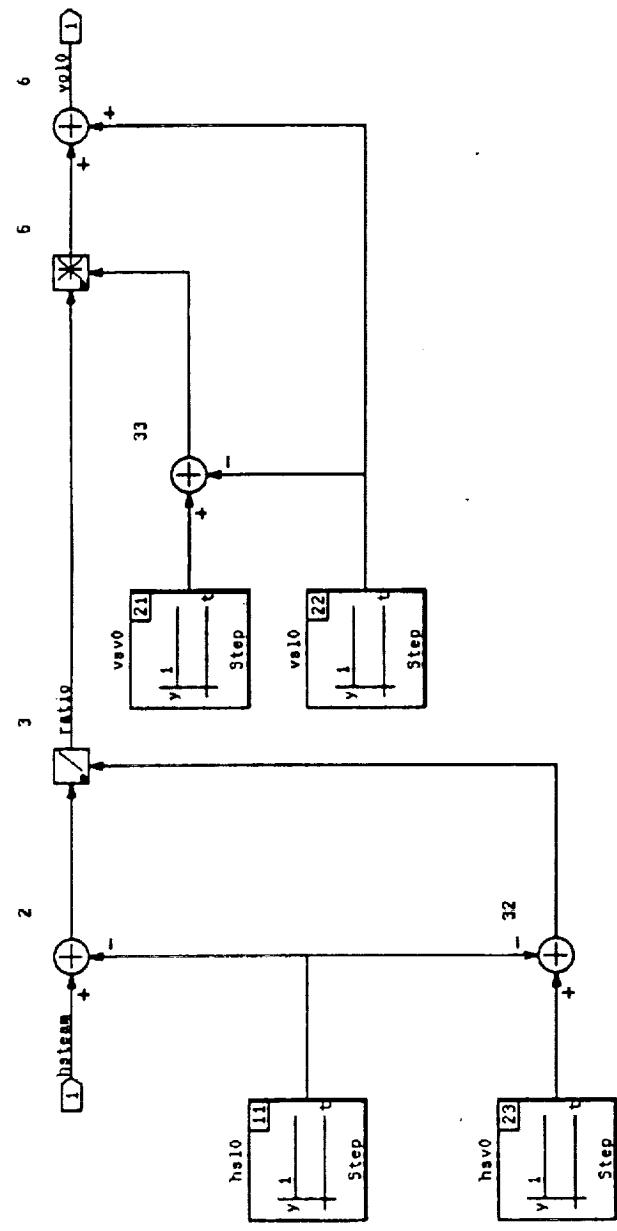
HINTS

Continuous Super-Block
Ext. Inputs Ext. Outputs
spec vol ratio 2



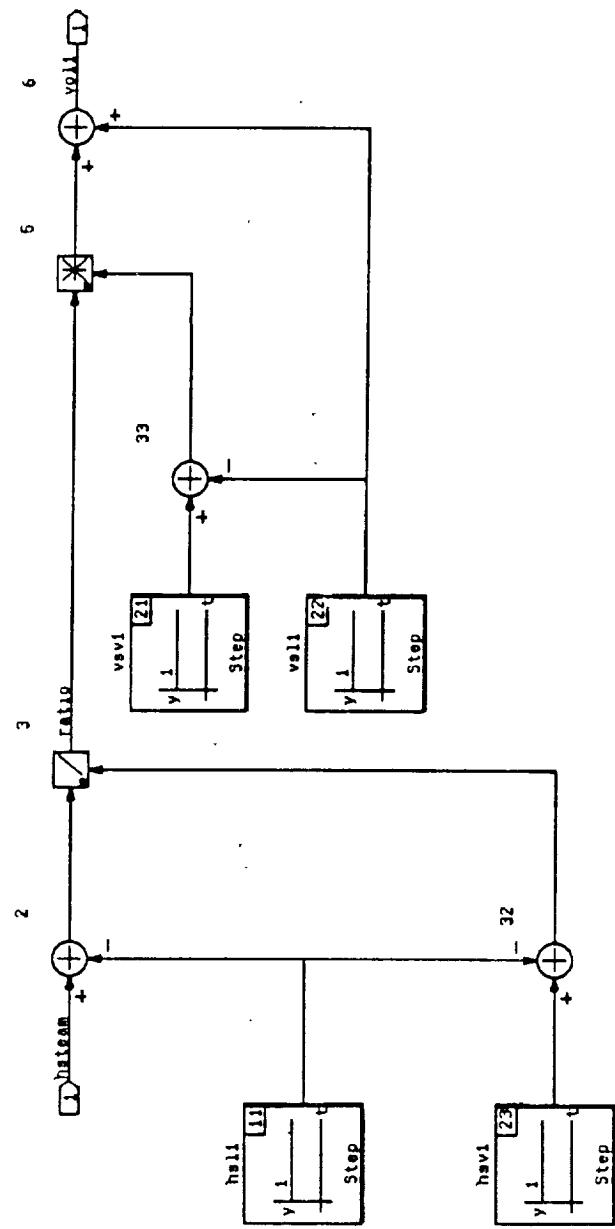
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
val0 1 1



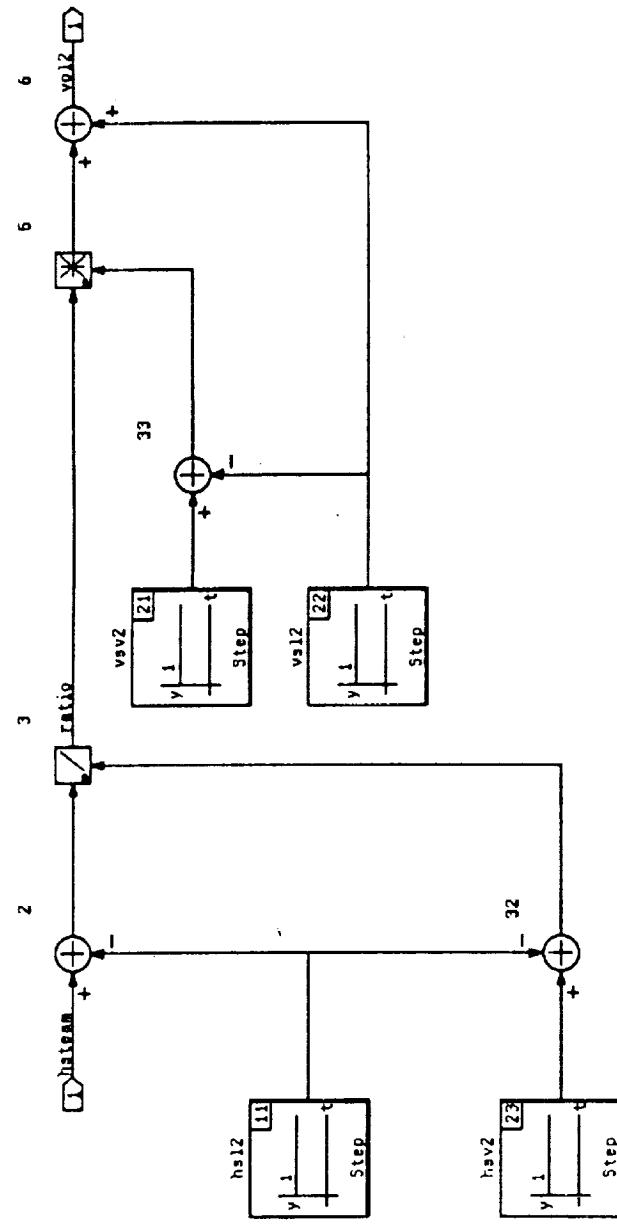
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Continuous Super-Block Ext. Inputs Ext. Outputs
 vol1 1 1



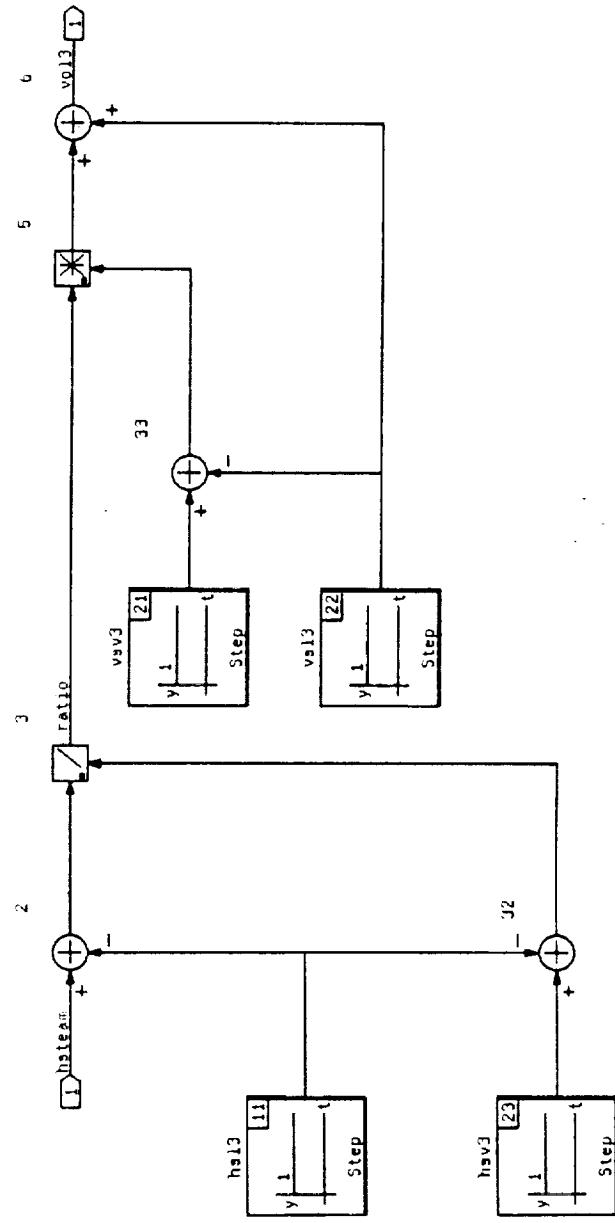
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
volz 1 1



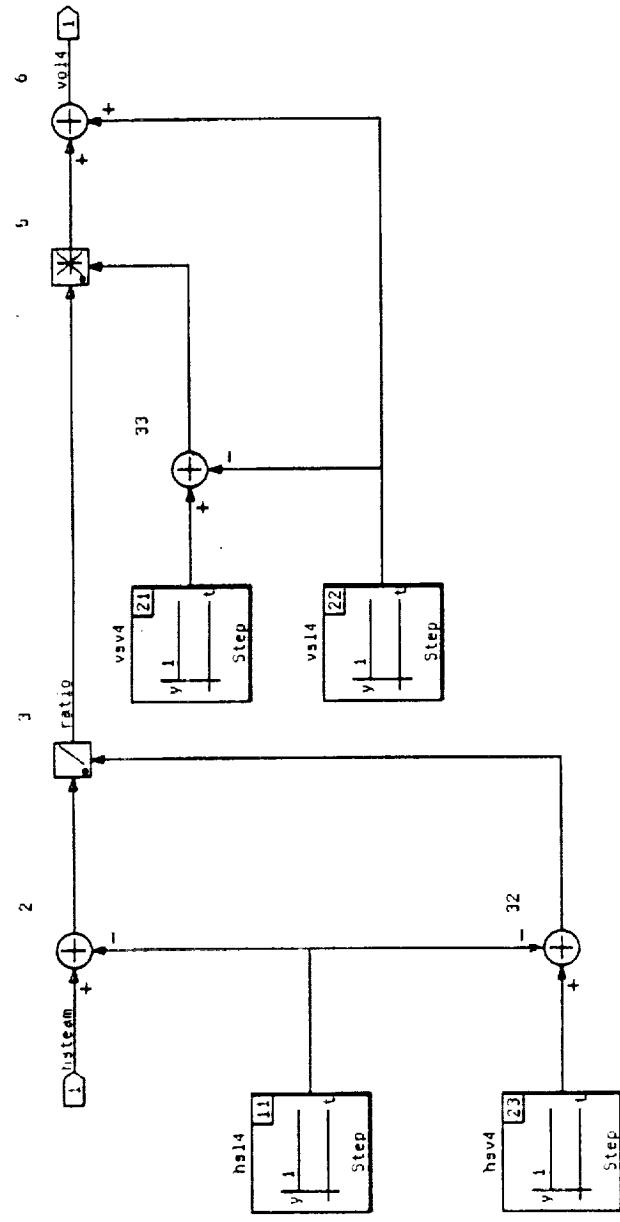
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
 vol3 1 1



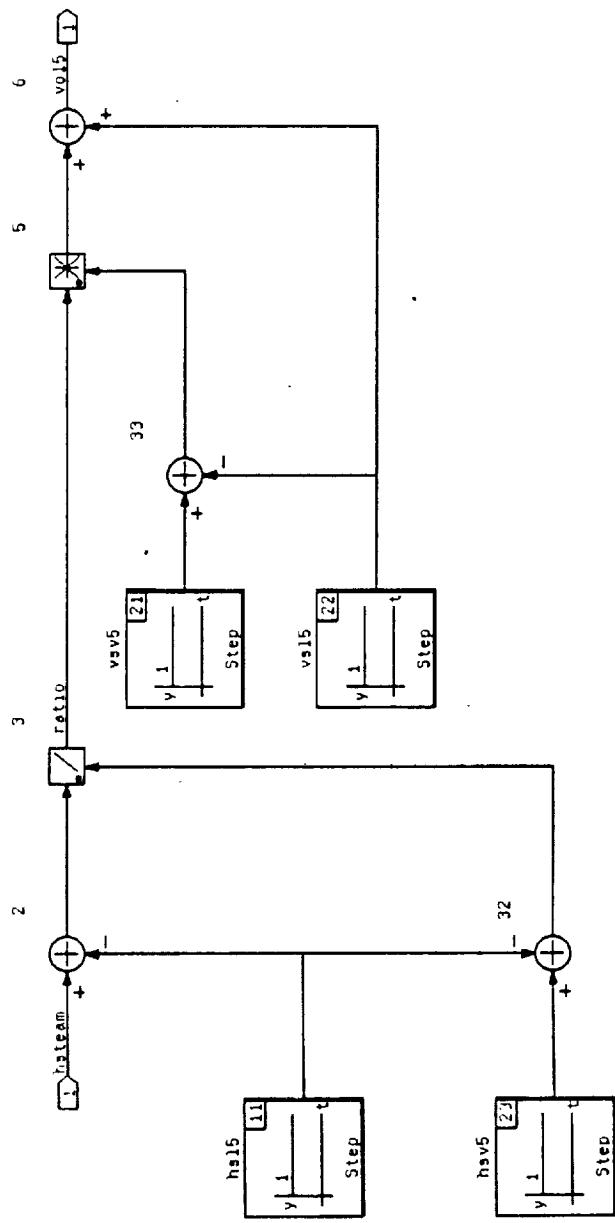
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
vol4 1 1



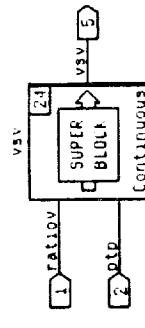
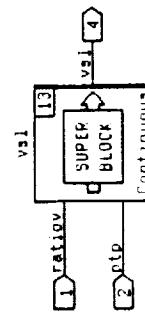
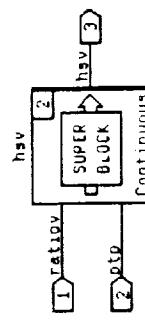
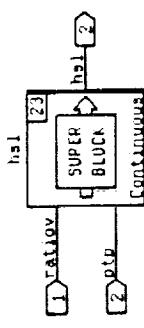
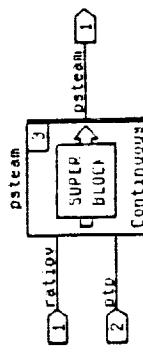
HINTS

Continuous Super-Block
vol5



HINTS

Continuous Super-Block
p and v_{sl}

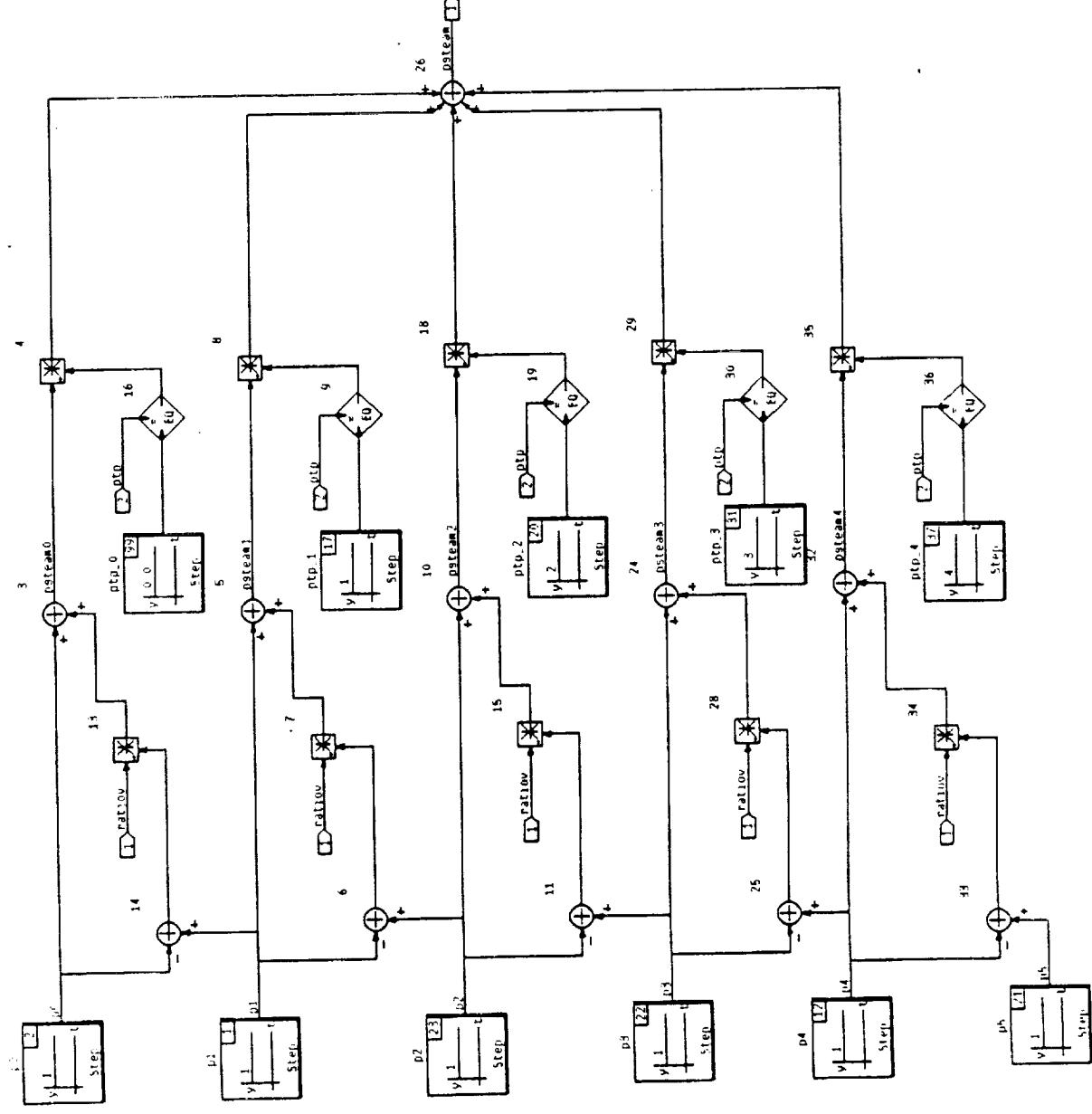


Ext. Inputs Ext. Outputs

2 5

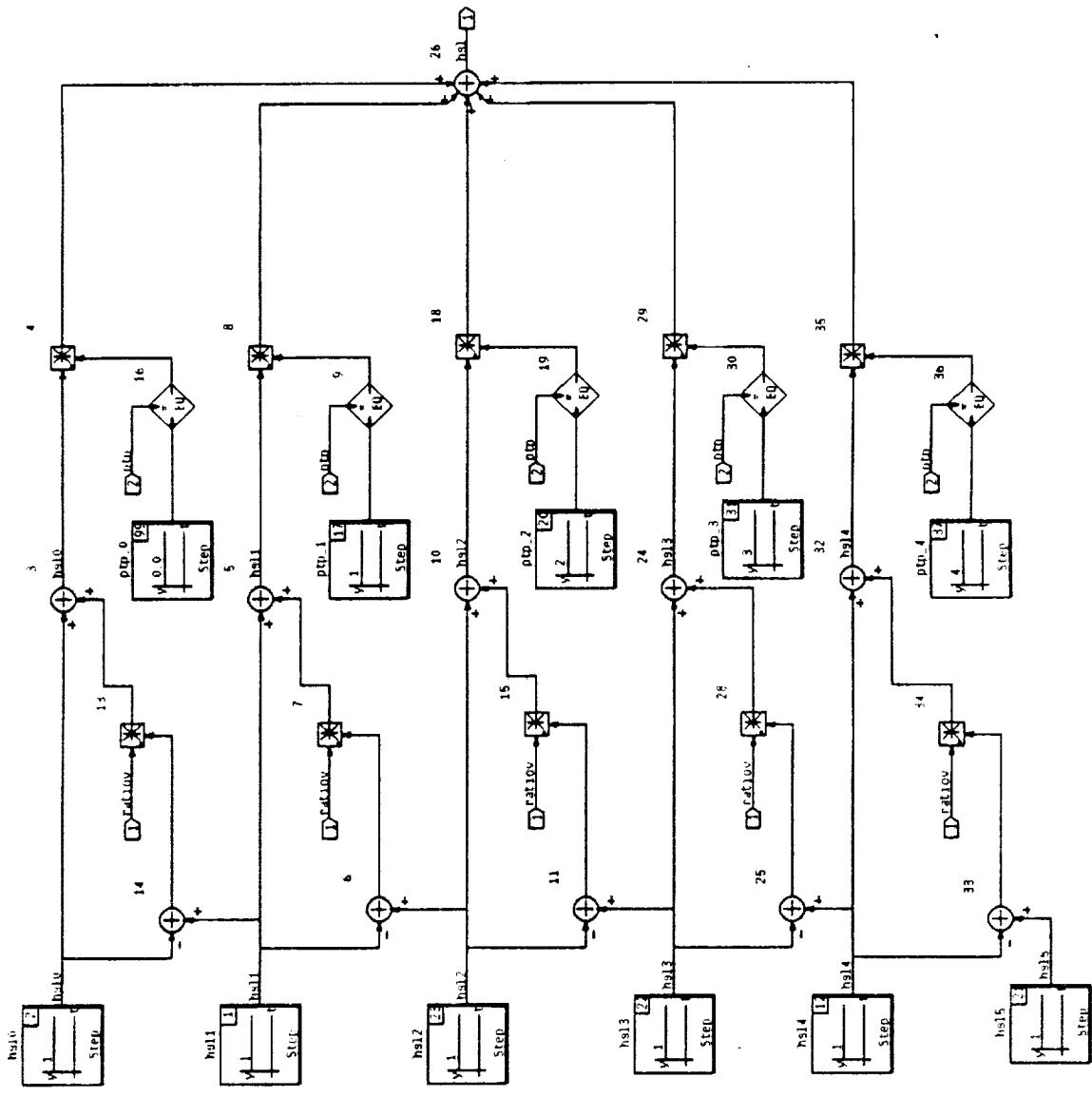
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
psteam 1



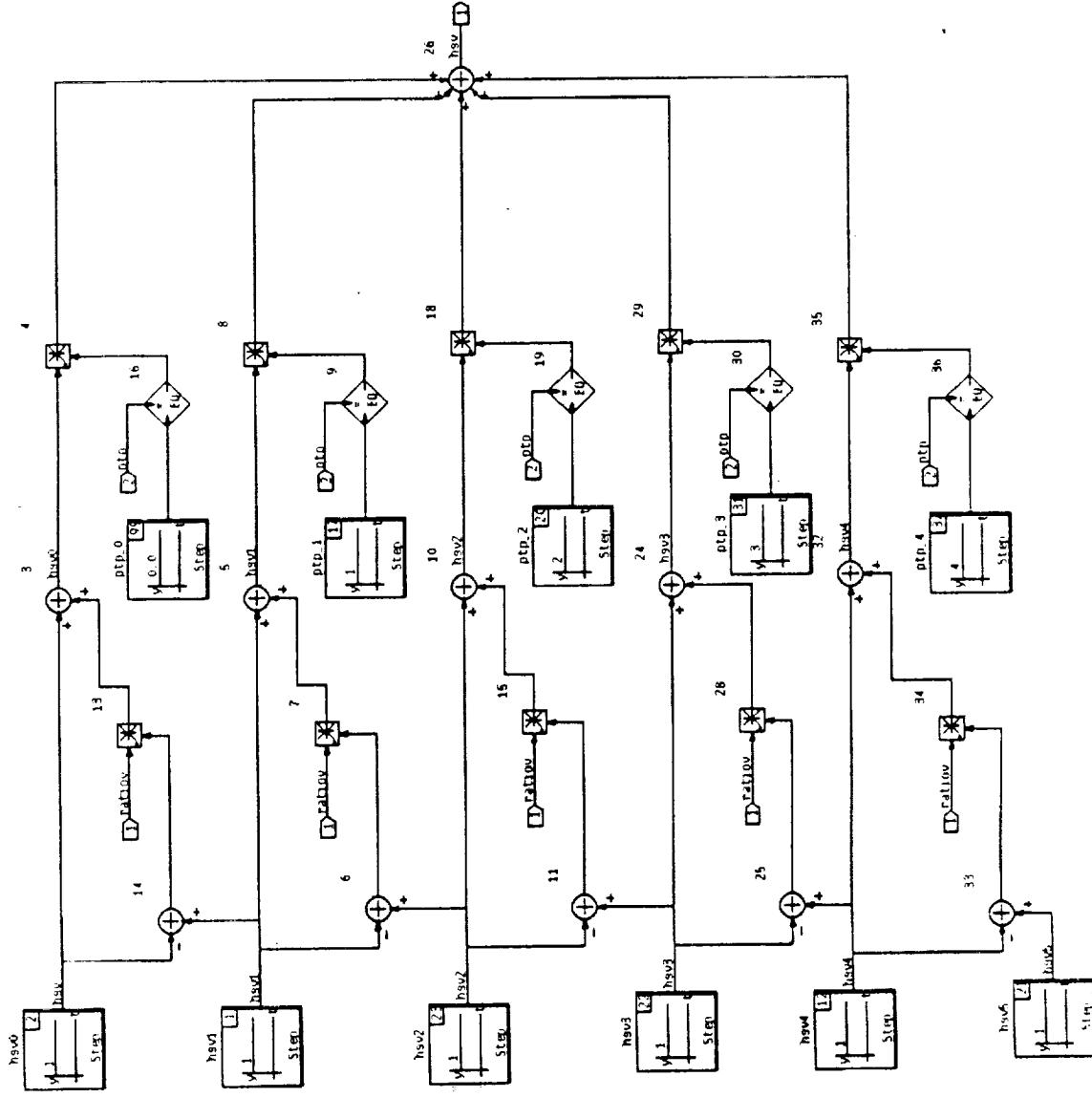
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
2 1



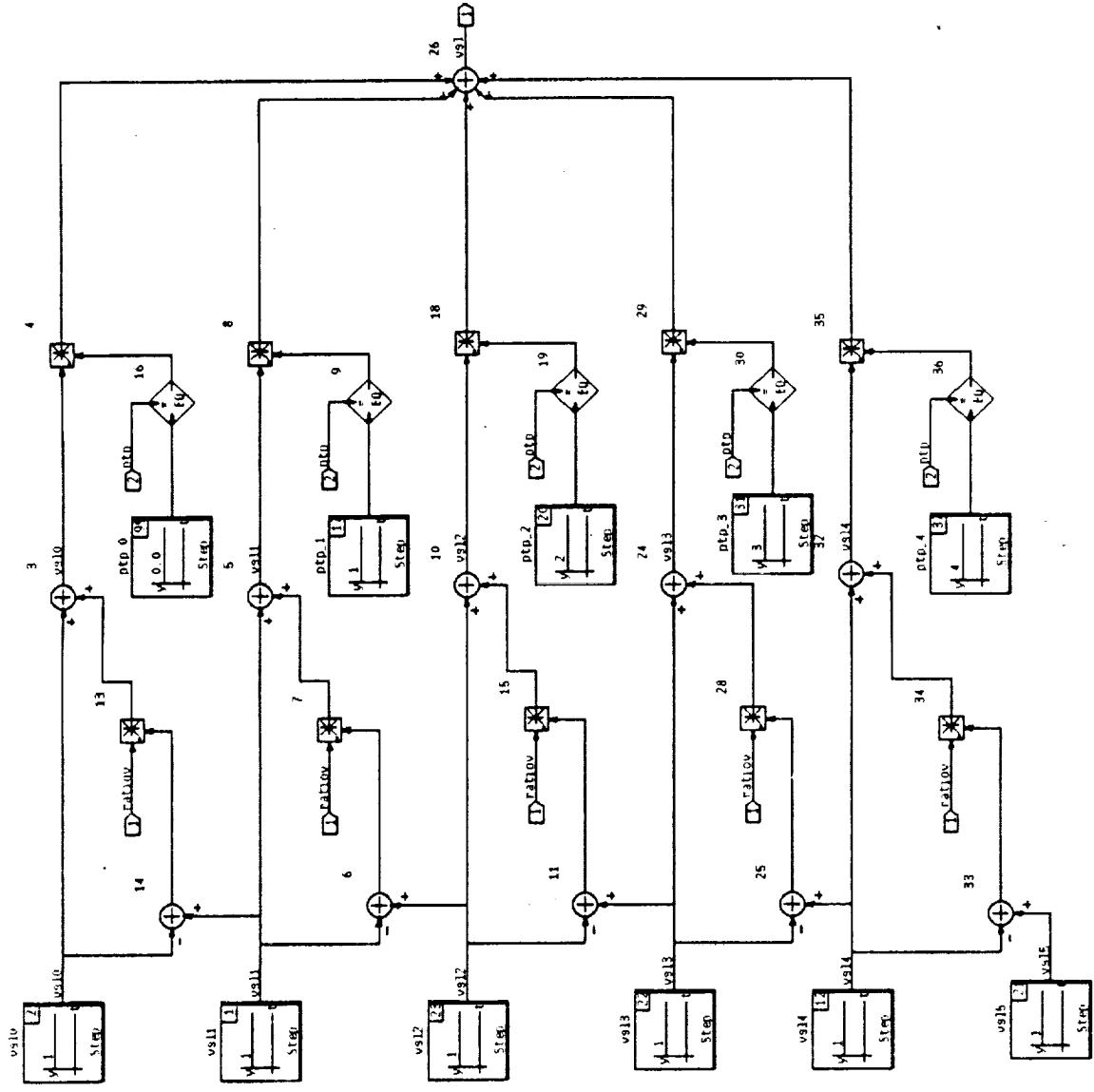
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
 hsu 1 1



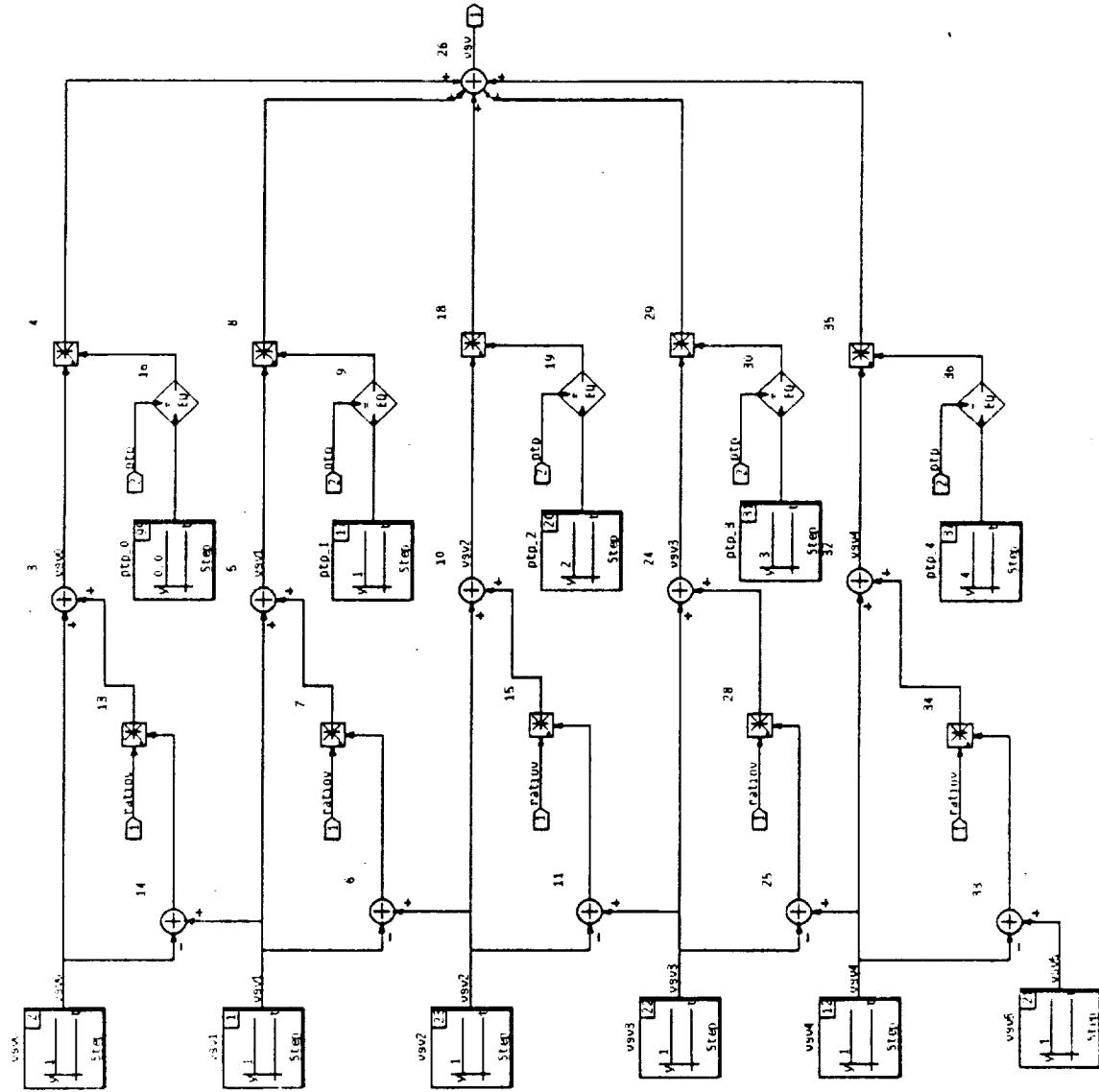
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
 vsl 2 1



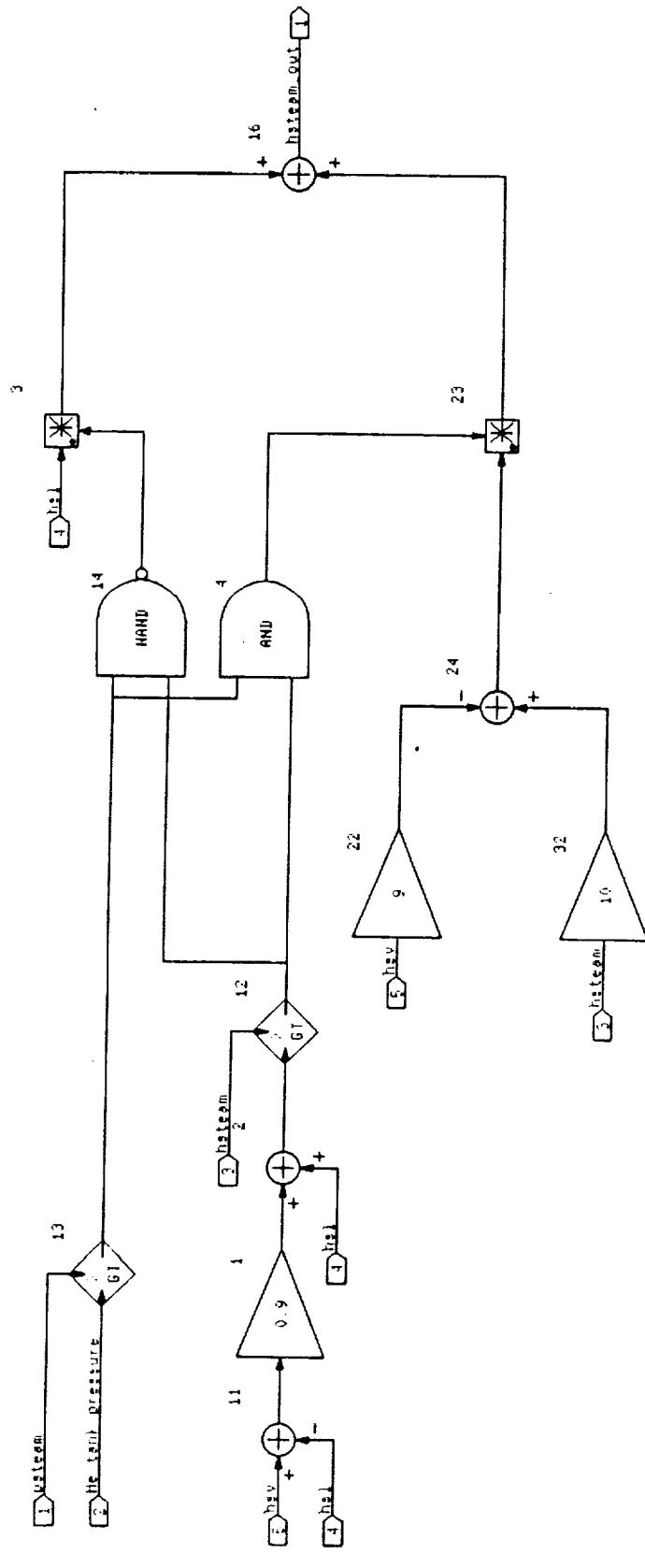
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
 v_{SV} 2 1



HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
Yesterdm_out E 1

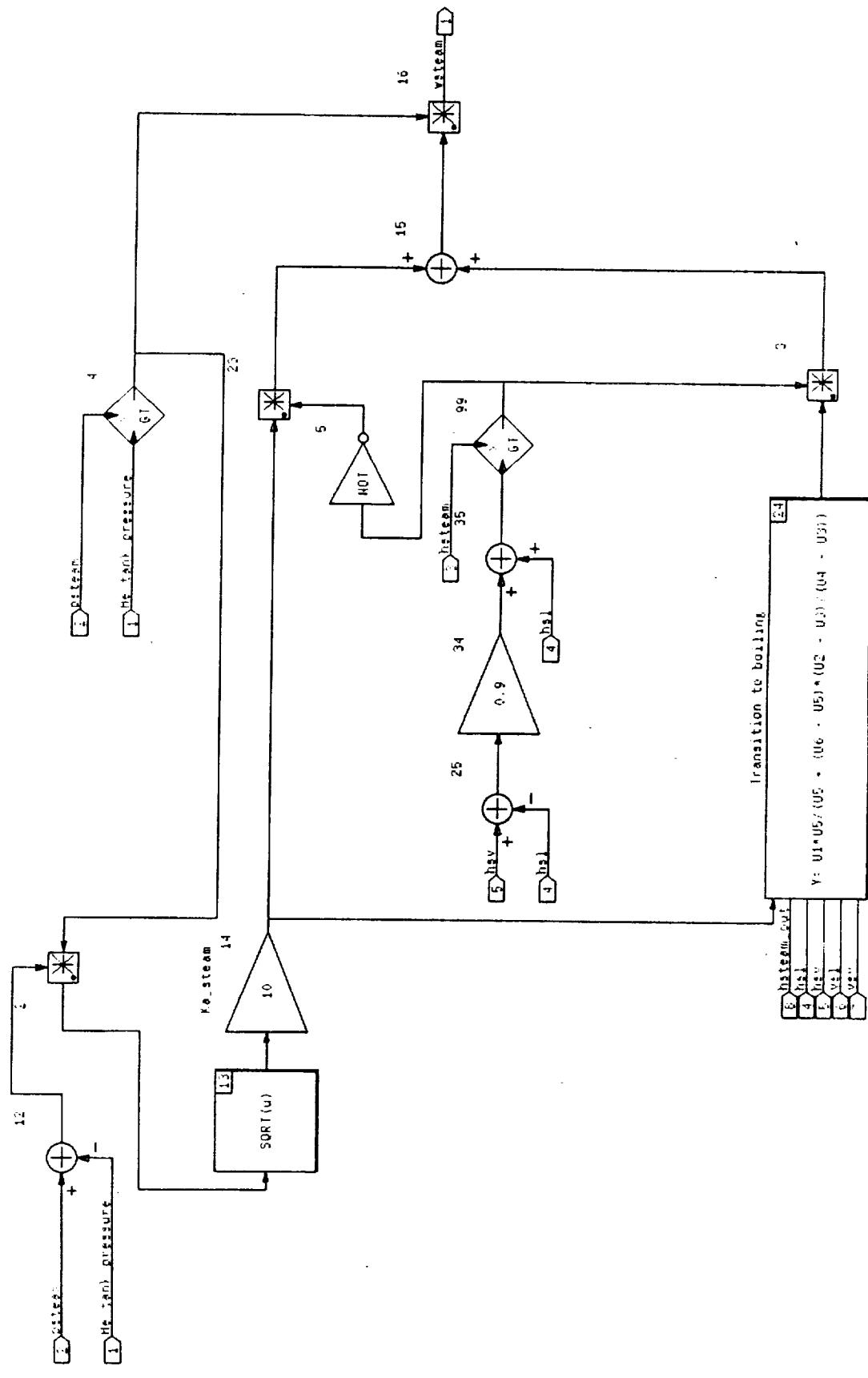


HINTS

Continuous Super-Block
w/steam

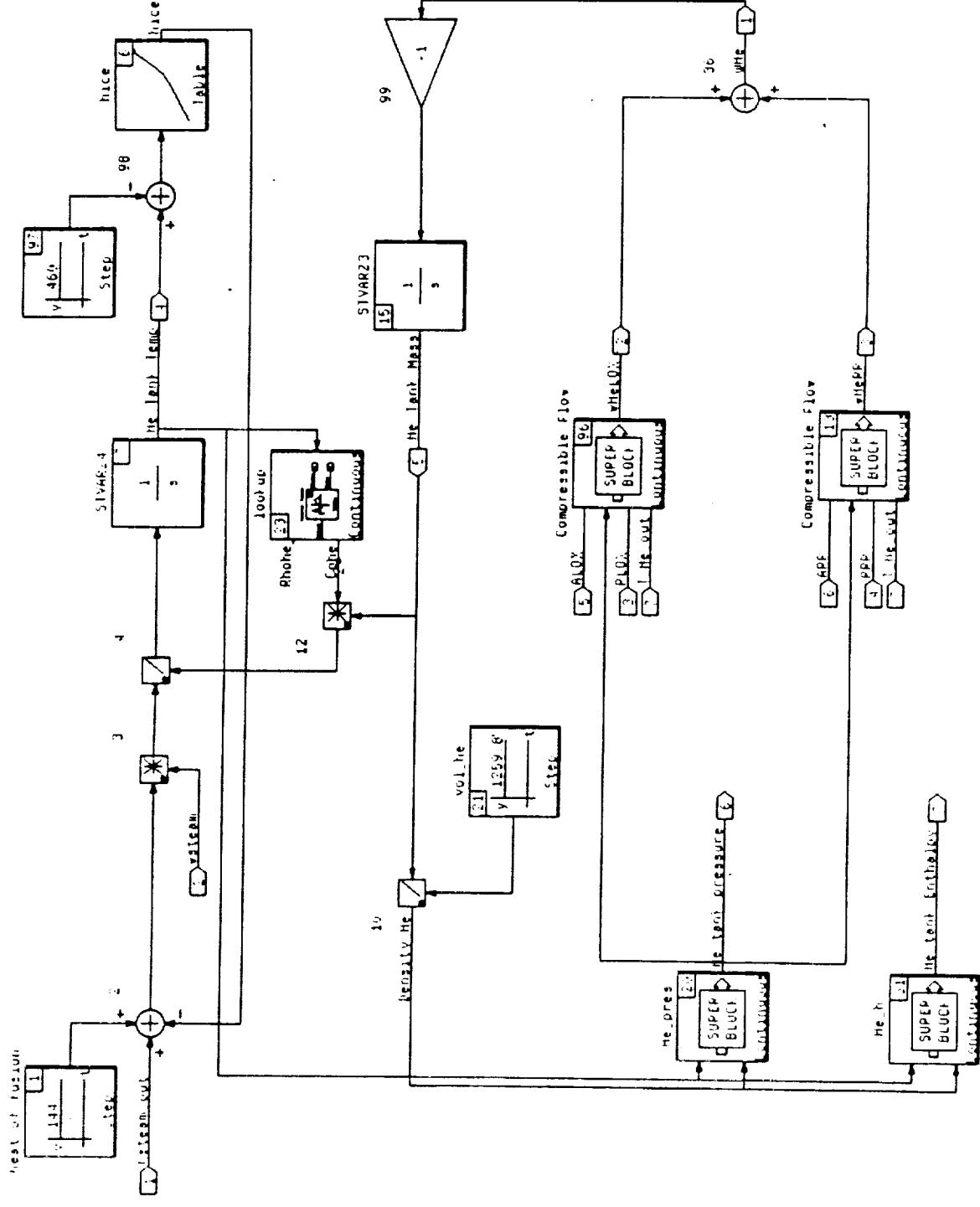
Ext. Inputs Ext. Outputs

8 1



HINTS

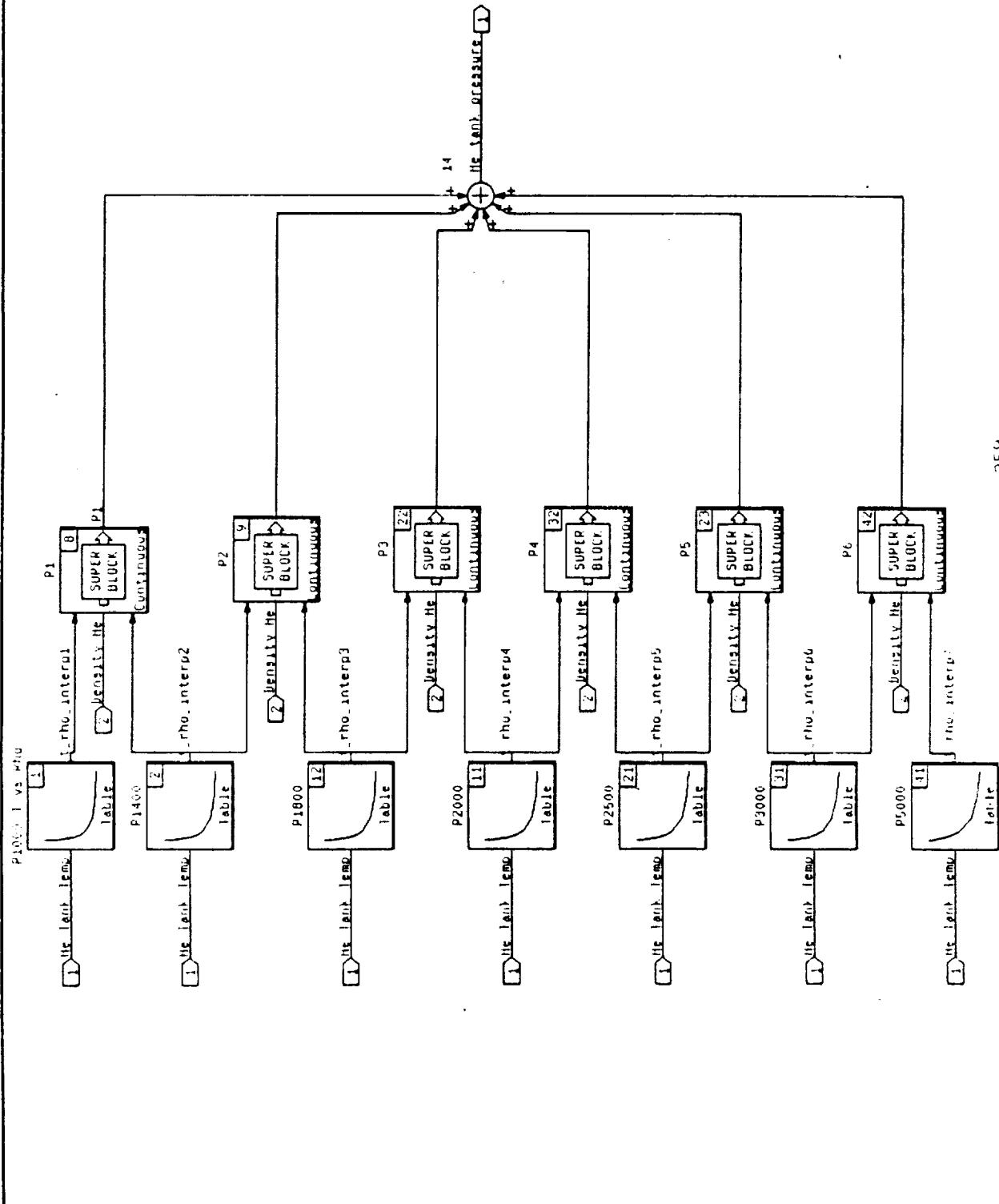
Continuous Super-Block Ext. Inputs Ext. Outputs
 Helium Bottle 7 7



HINTS

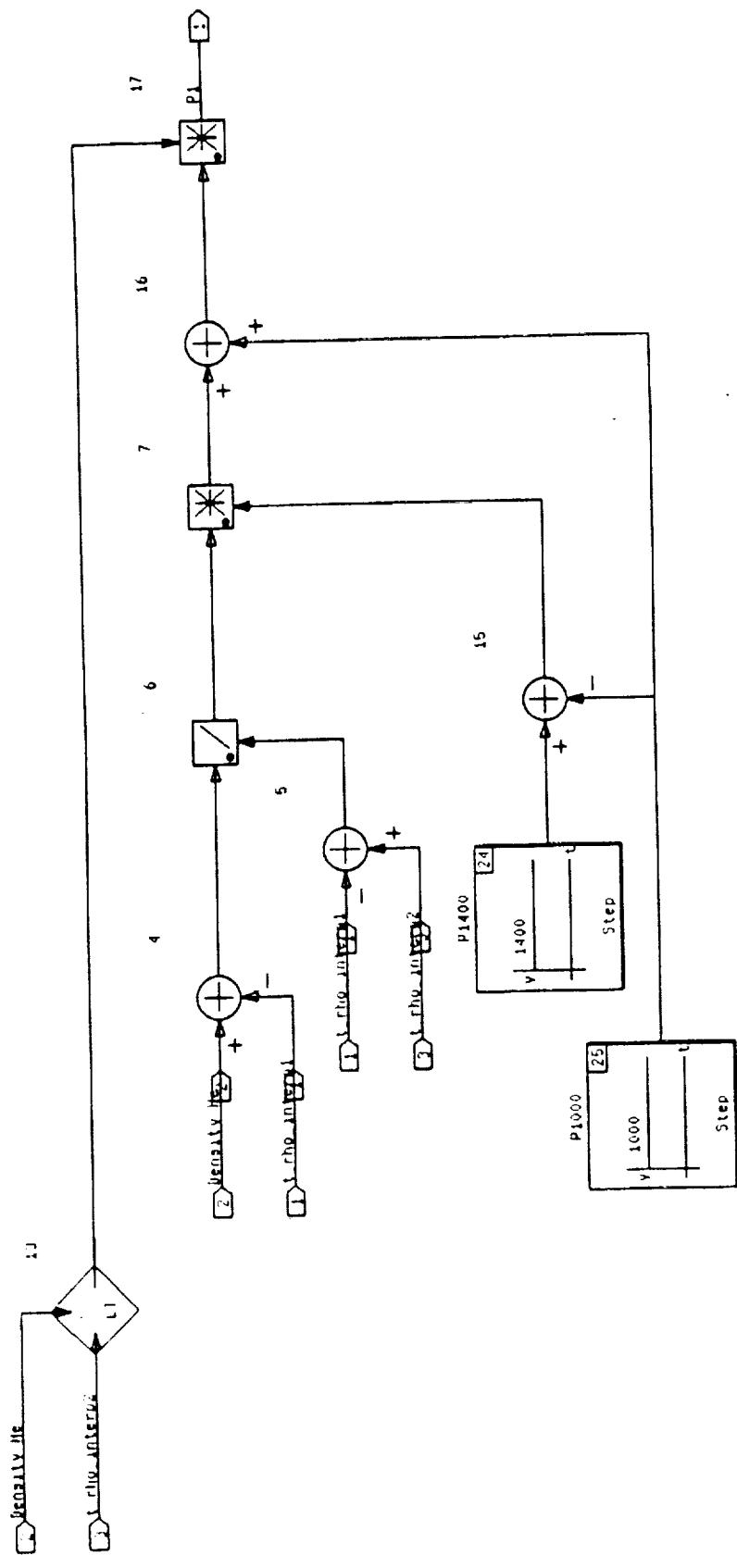
Continuous Super-Block
He_pres

Ext. Inputs Ext. Outputs
1 2 1



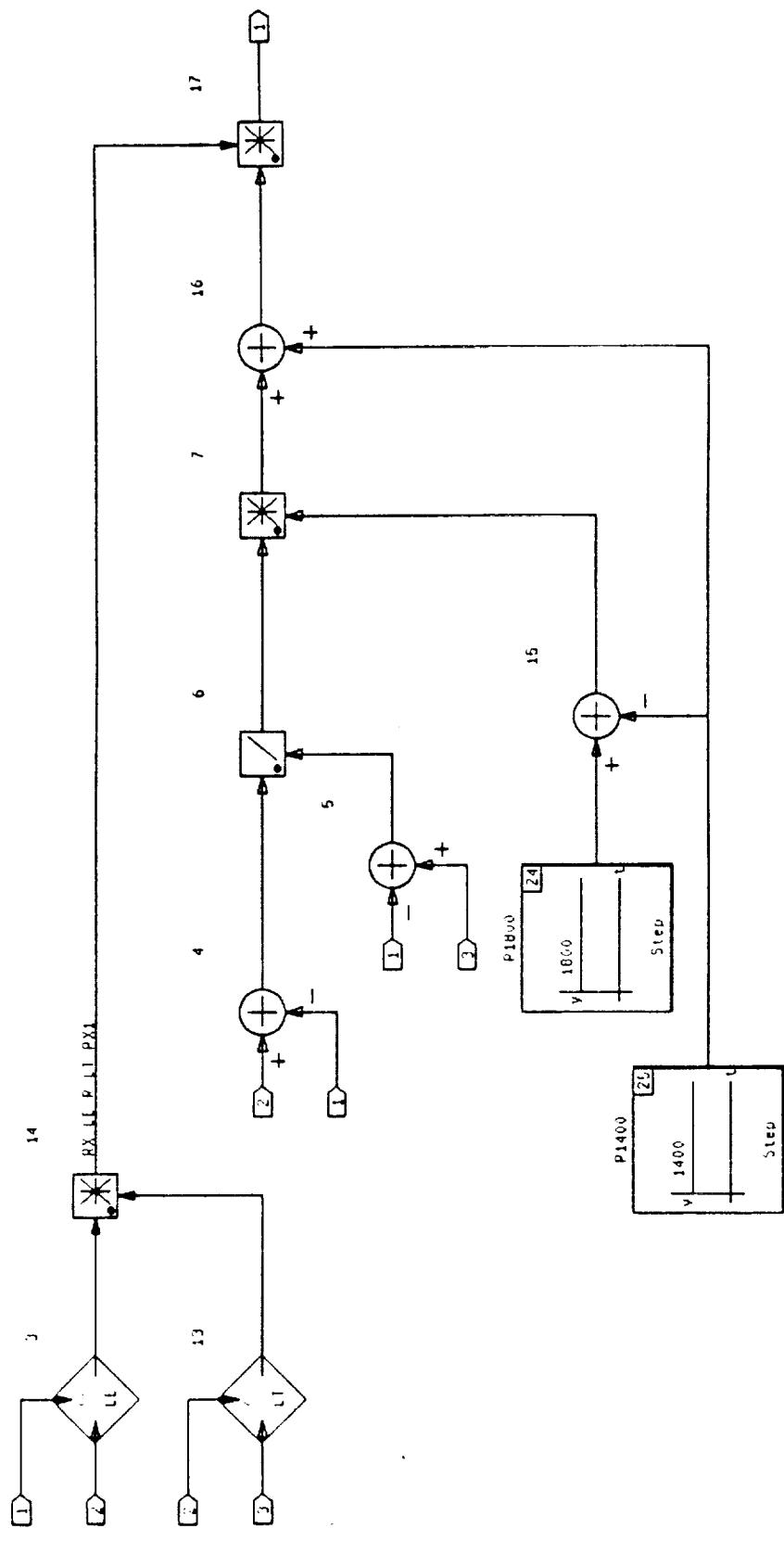
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
P1 3 1



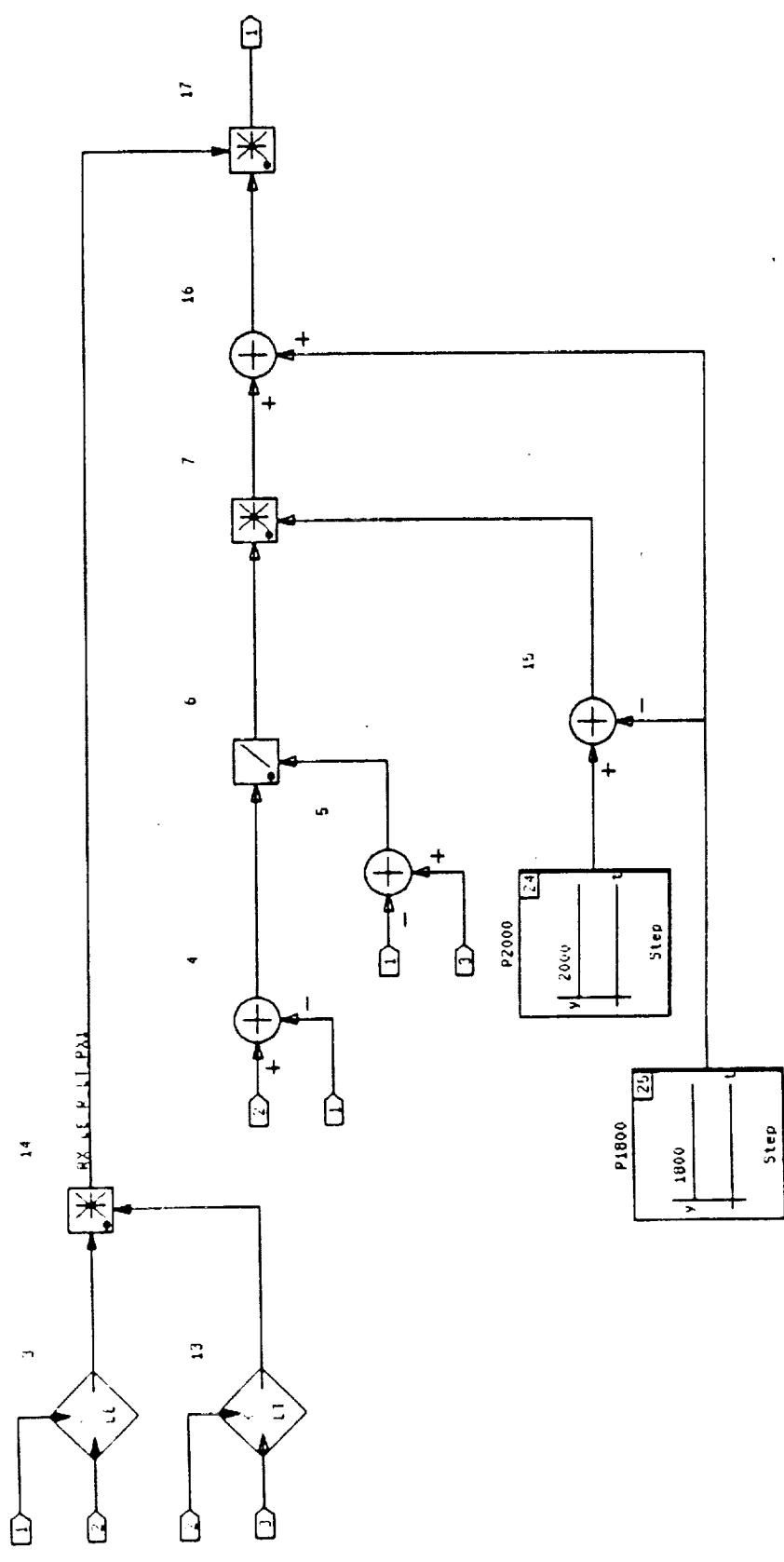
HINTS

Continuous Super-Block P2 Ext. Inputs P2 Ext. Outputs 1



HINTS

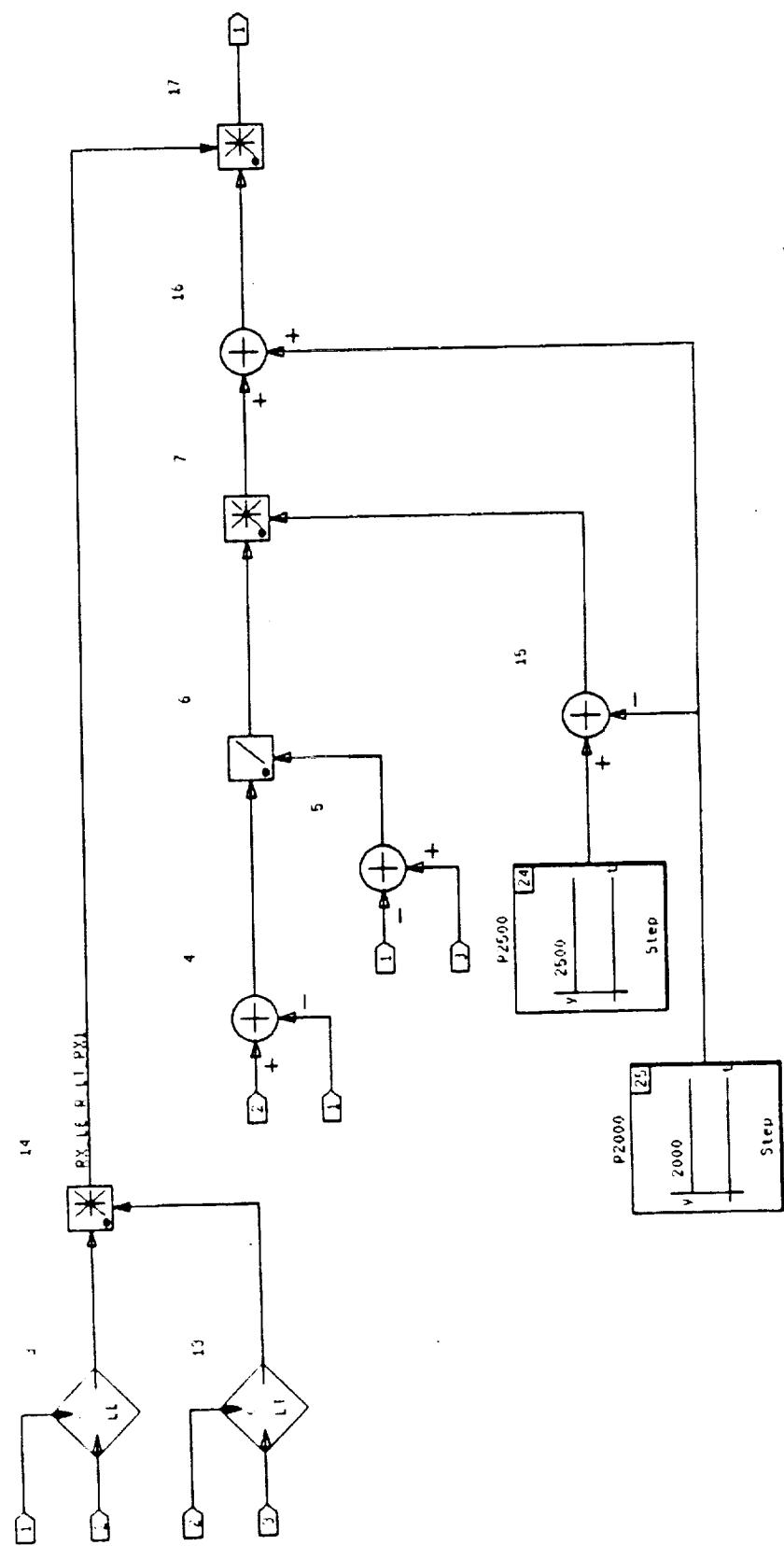
Continuous Super-Block Ext. Inputs Ext. Outputs
P3 3 1



HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
 3 1

p4



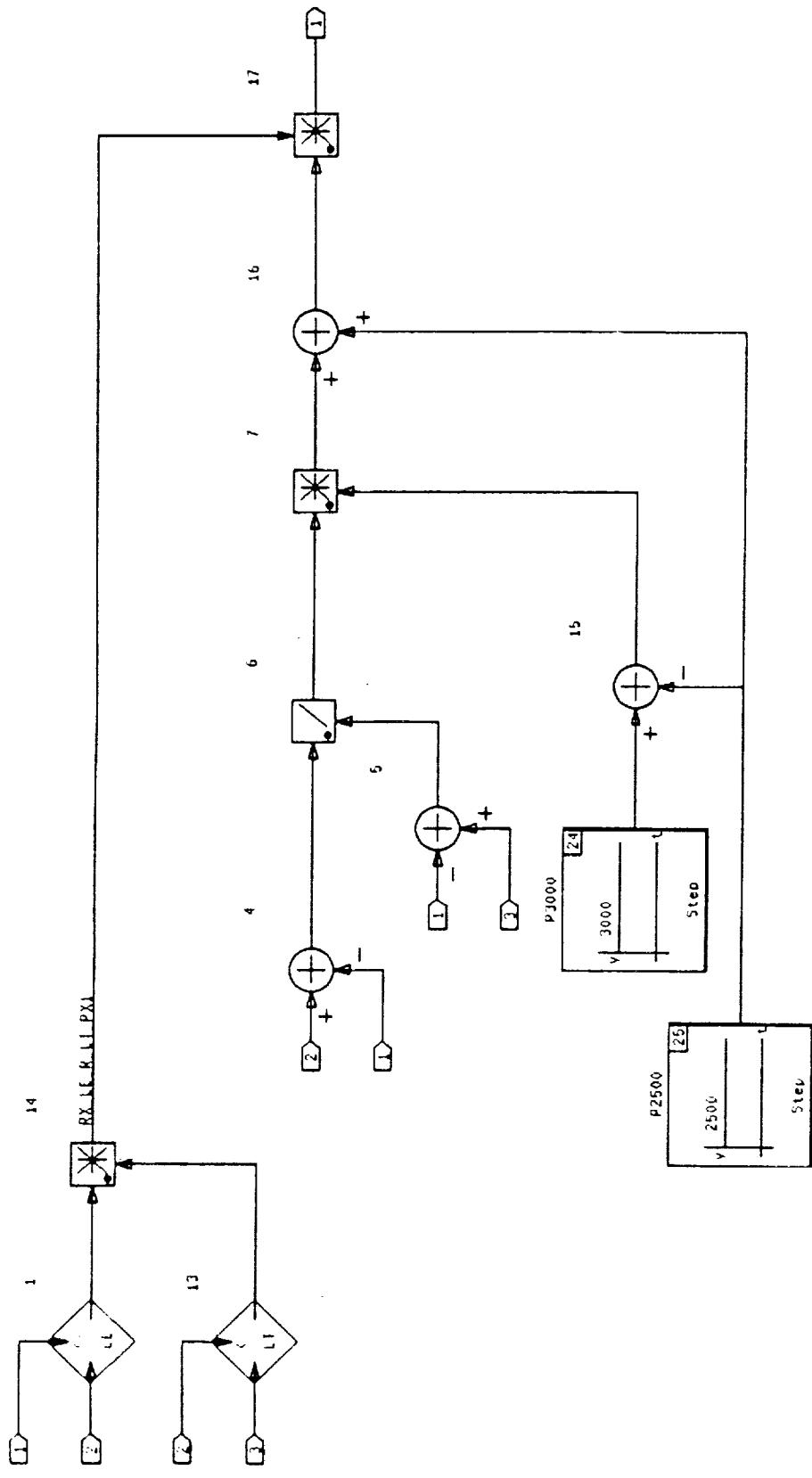
HINTS

Continuous Super-Block
PS

Ext. Inputs Ext. Outputs

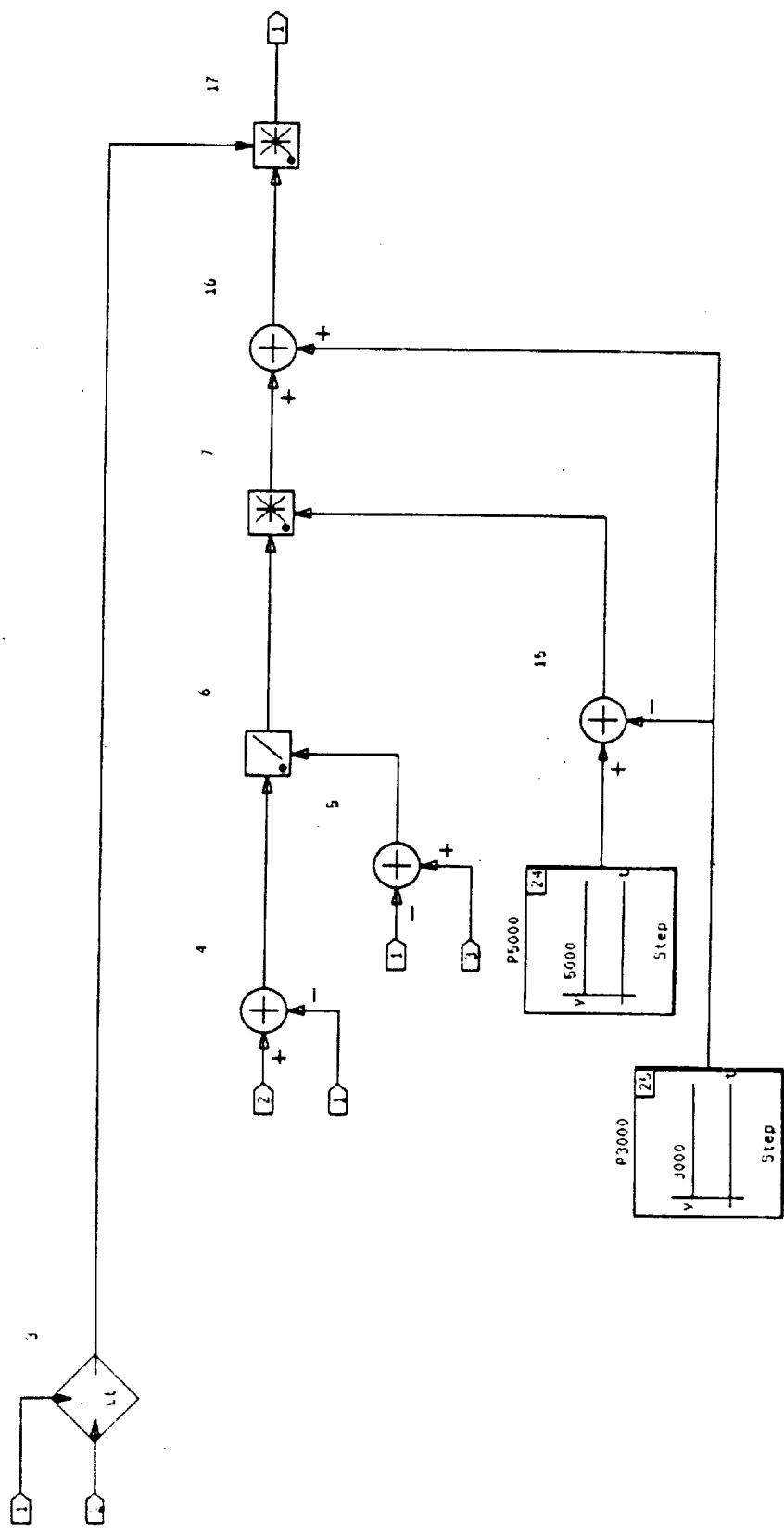
3

1



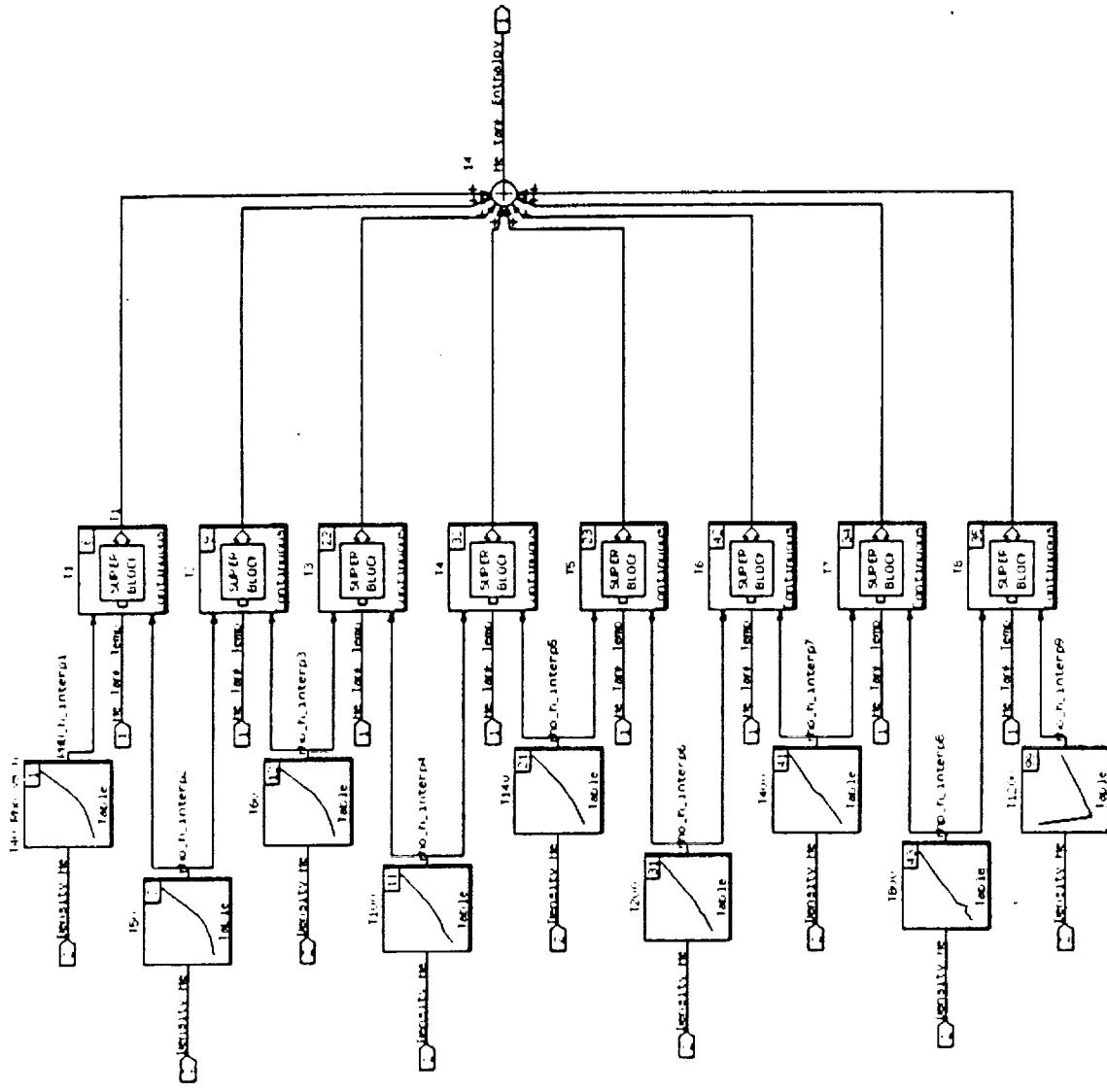
HINTS

Continuous Super-Block
P6
Ext. Inputs 3
Ext. Outputs 1



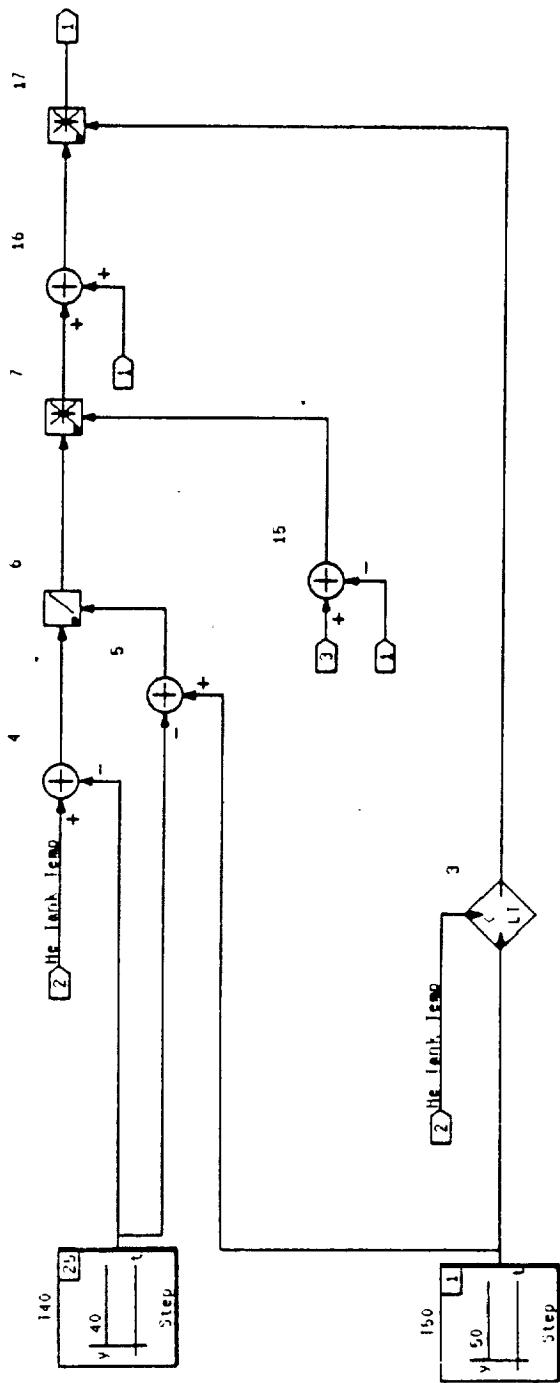
HINTS

Continuous Super-Block He_h



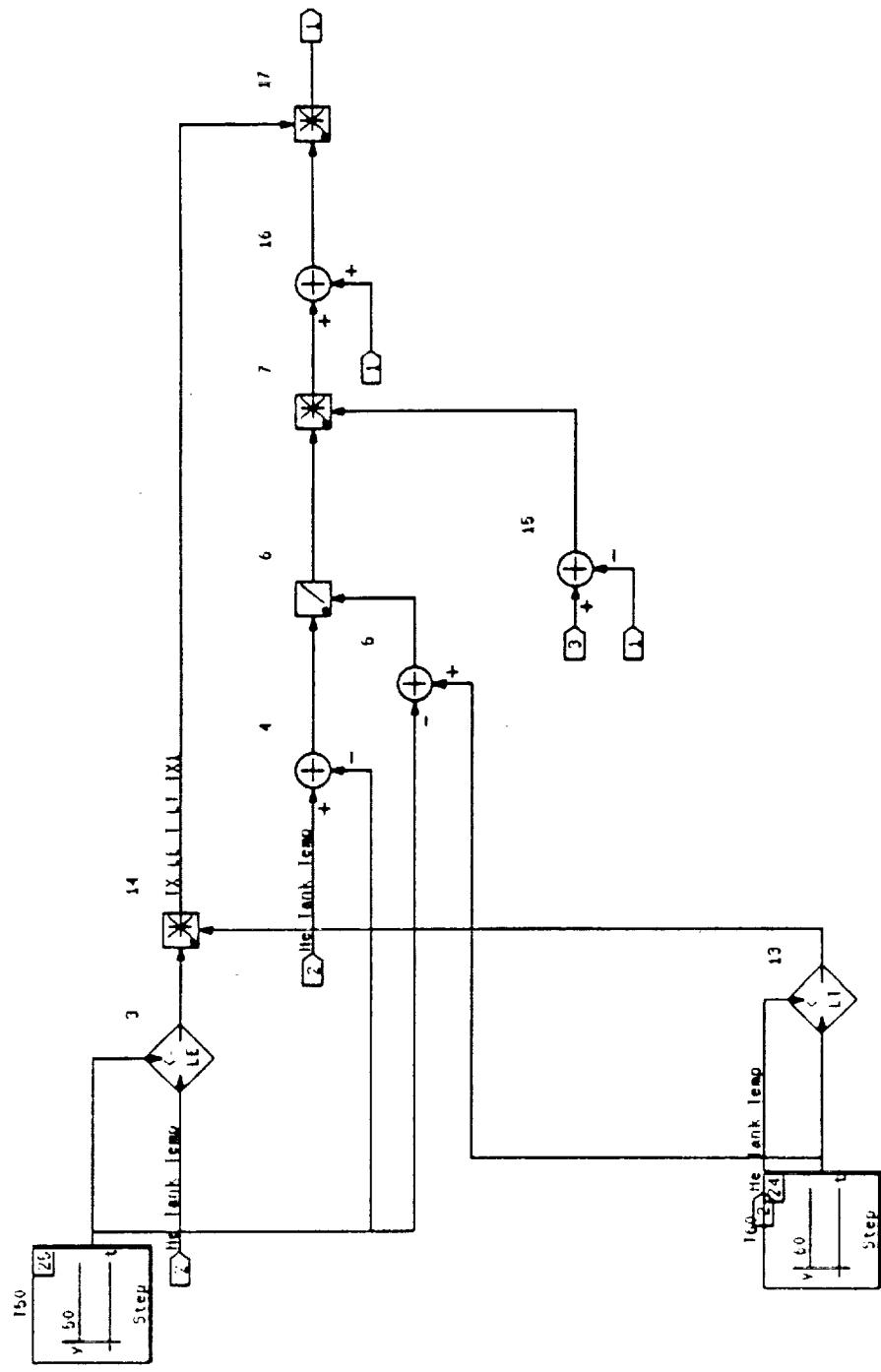
HINTS

Continuous Super-block Ext. Inputs Ext. Outputs
T1 3 1



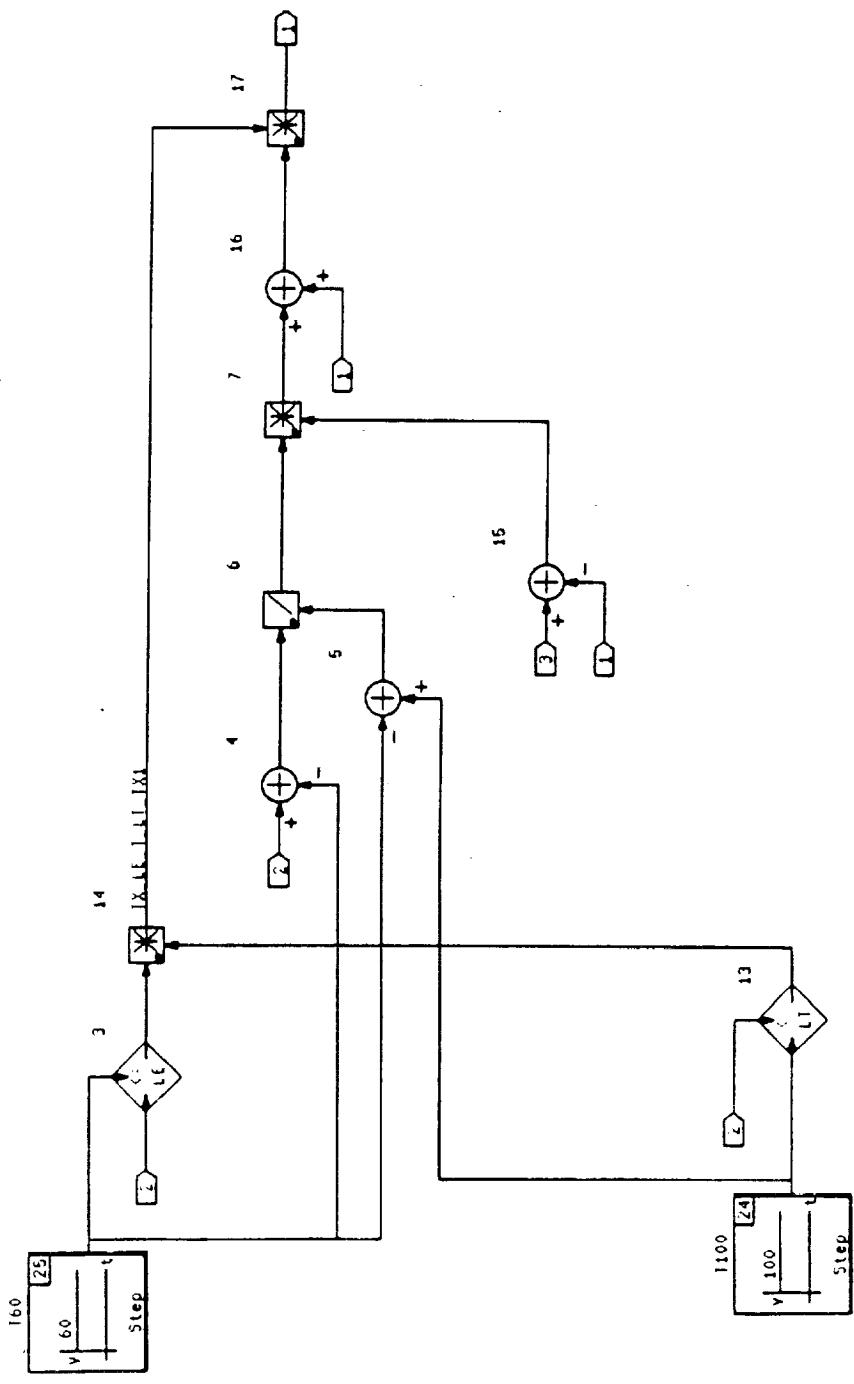
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
T2 3 1



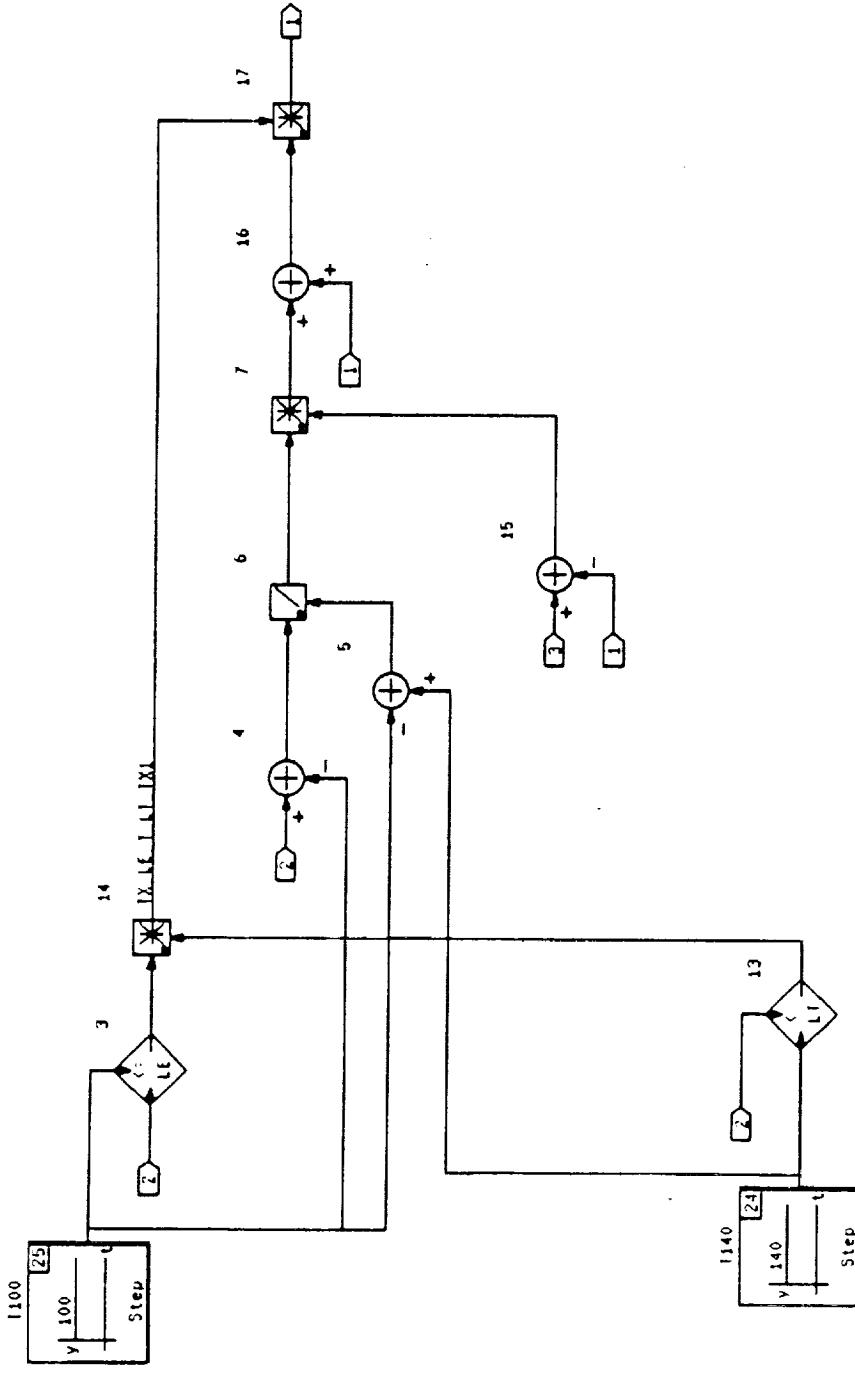
HINTS

Continuous Super-Block	Ext. Inputs	Ext. Outputs
T ₃	3	1



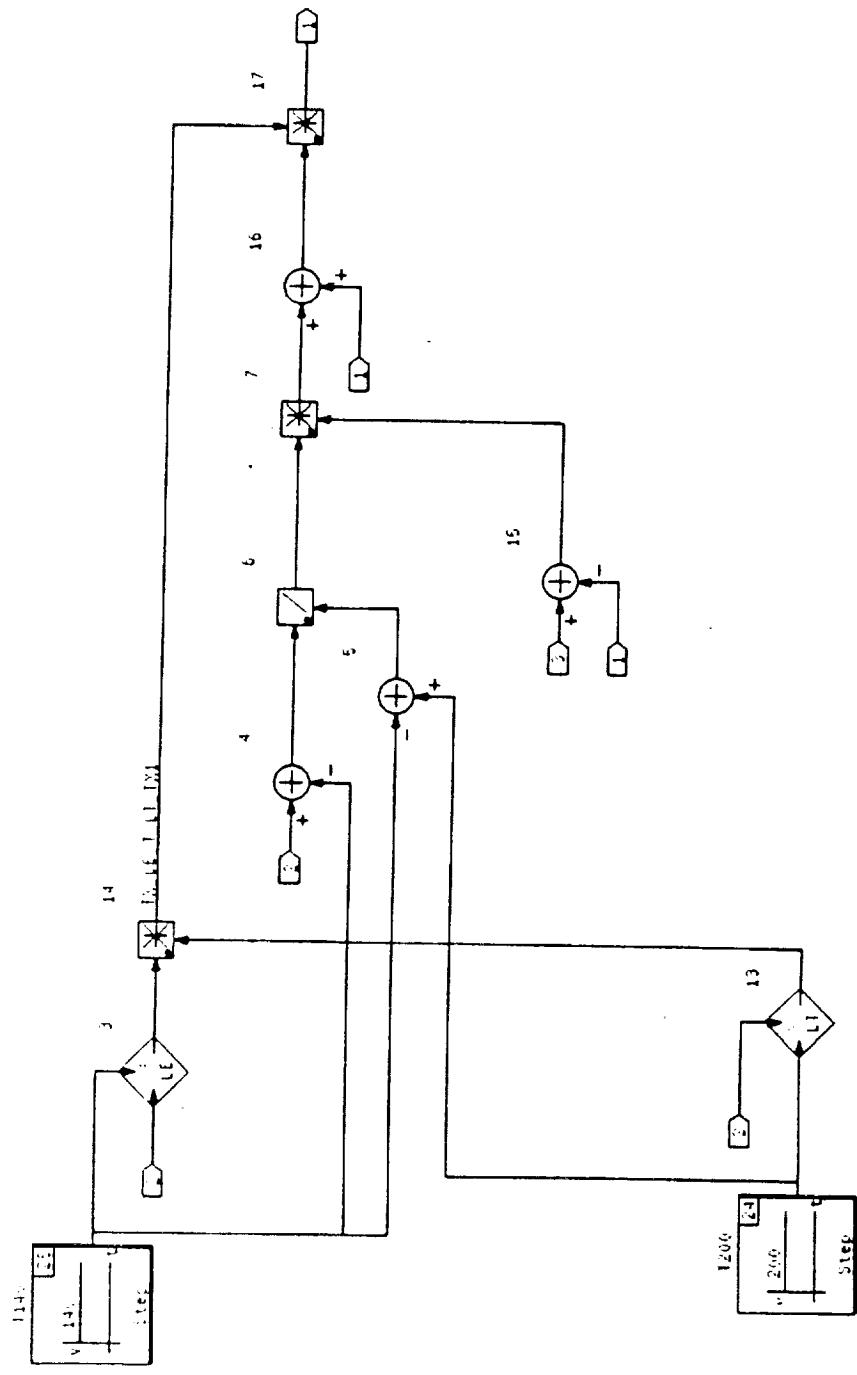
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
14 3 1



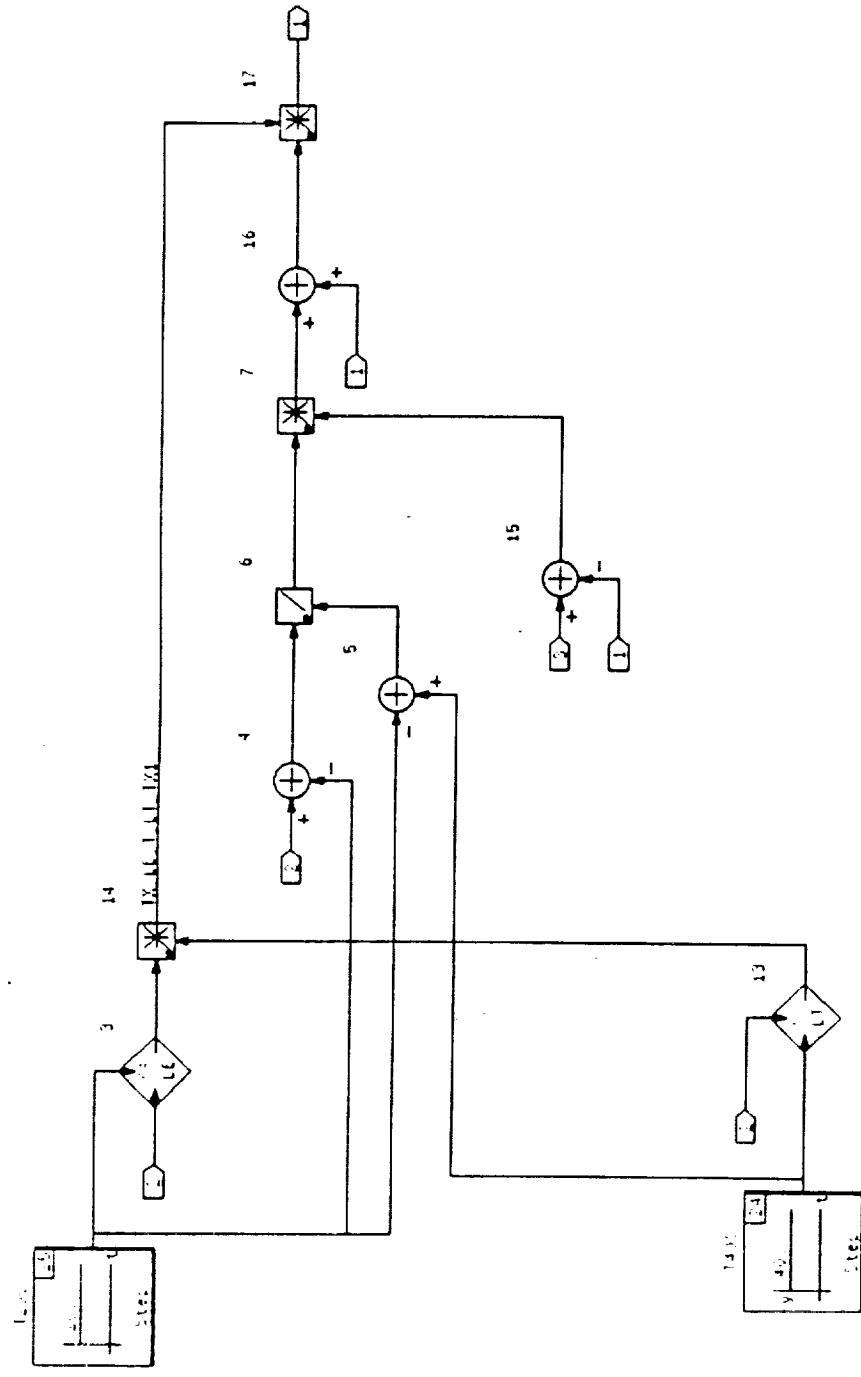
HINTS

Continuous Super-Block
T5 Ext. Inputs Ext. Outputs
5 1



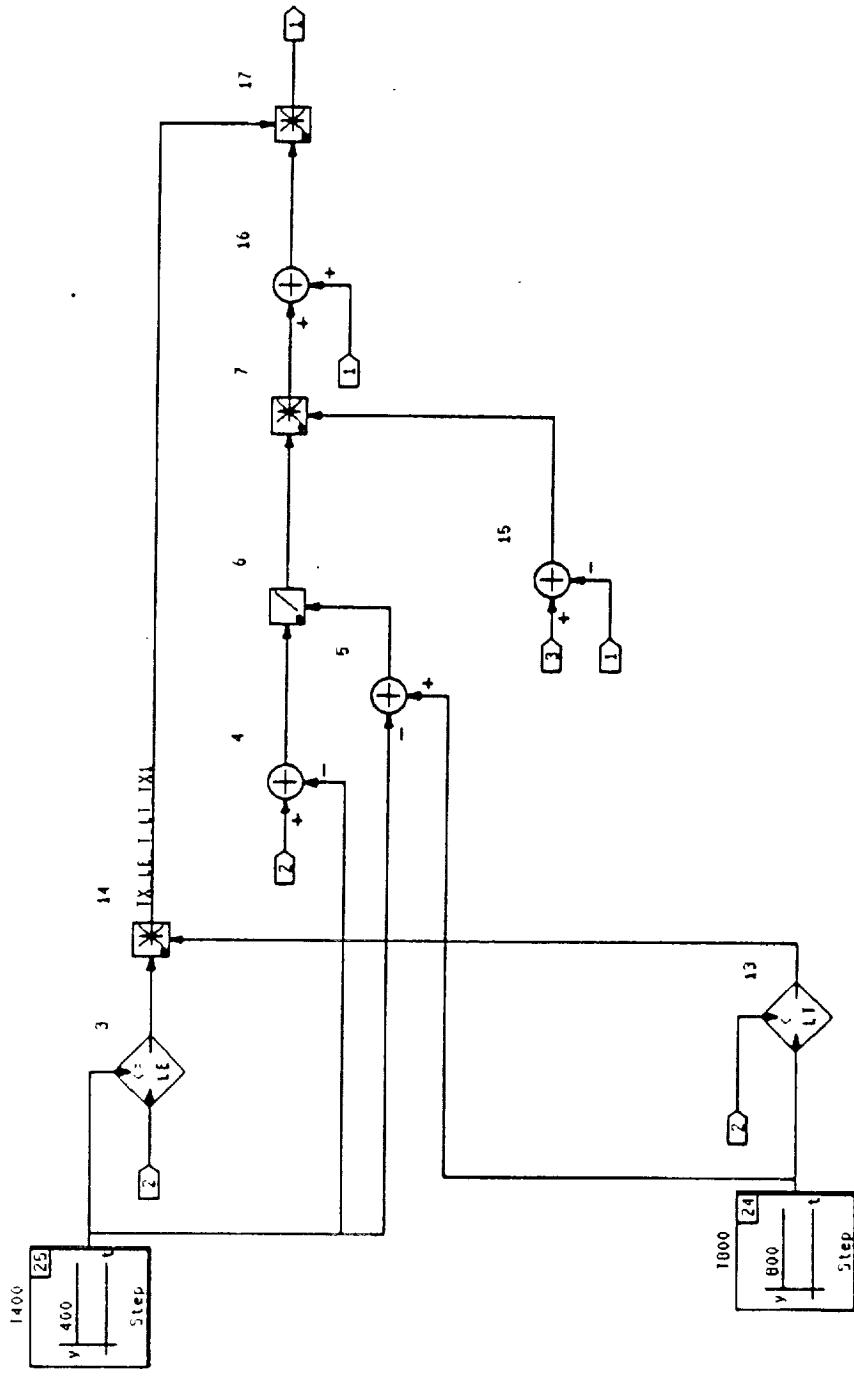
HINTS

Continuous Super-BLOCK Ext. Inputs Ext. Outputs
T6 3 1



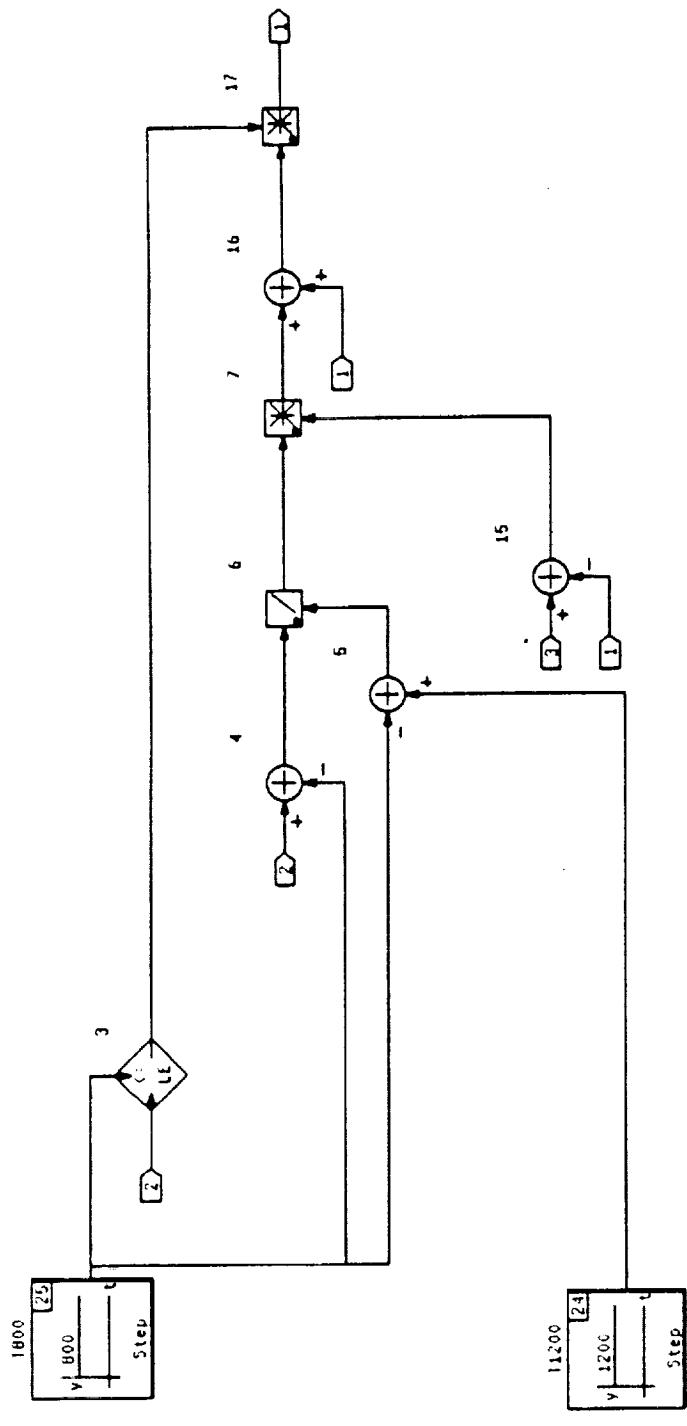
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
17 3 1



HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
T₈ 3 1



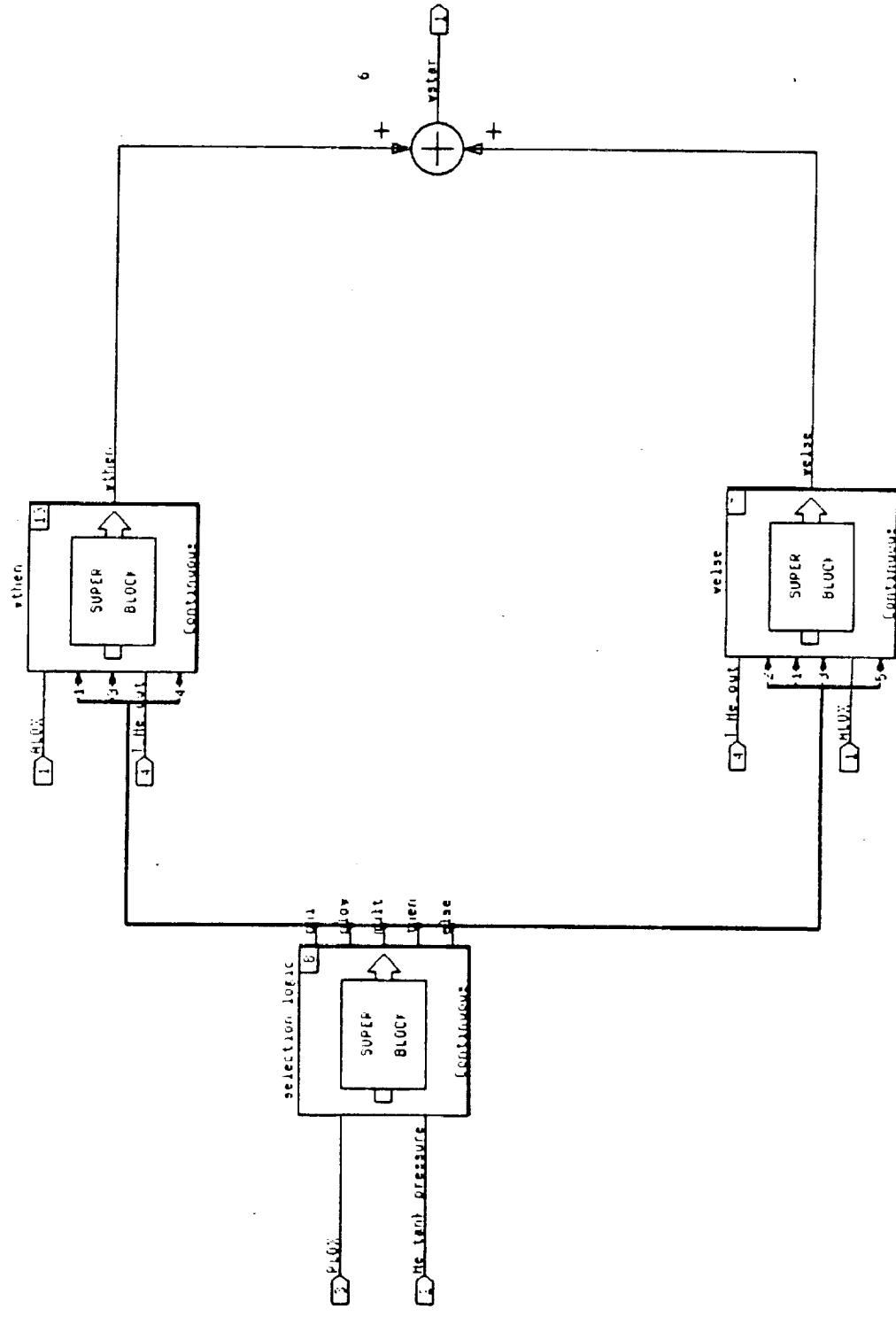
HINTS

Continuous Super-BLOCK
Compressible Flow

Ext. Inputs Ext. Outputs

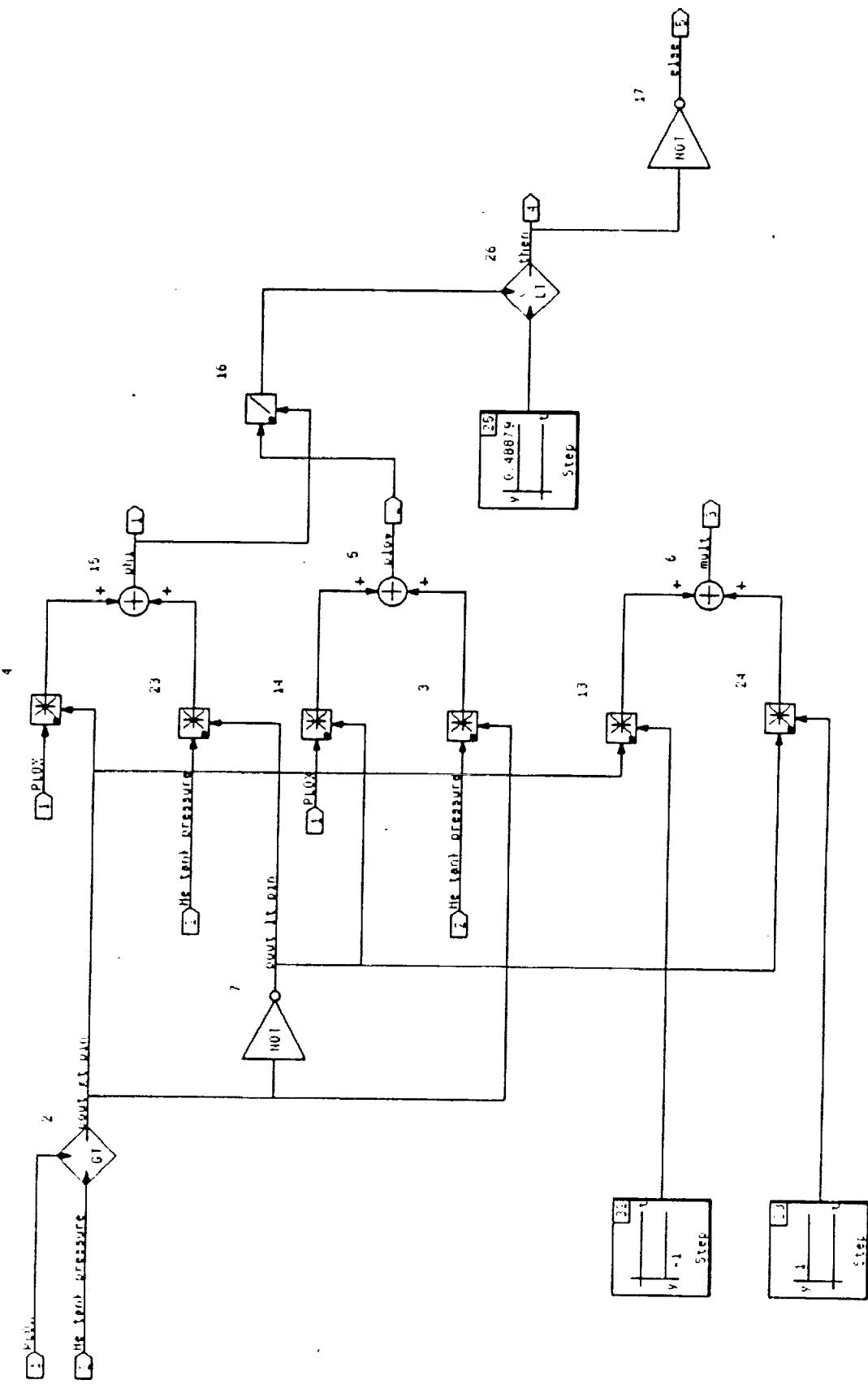
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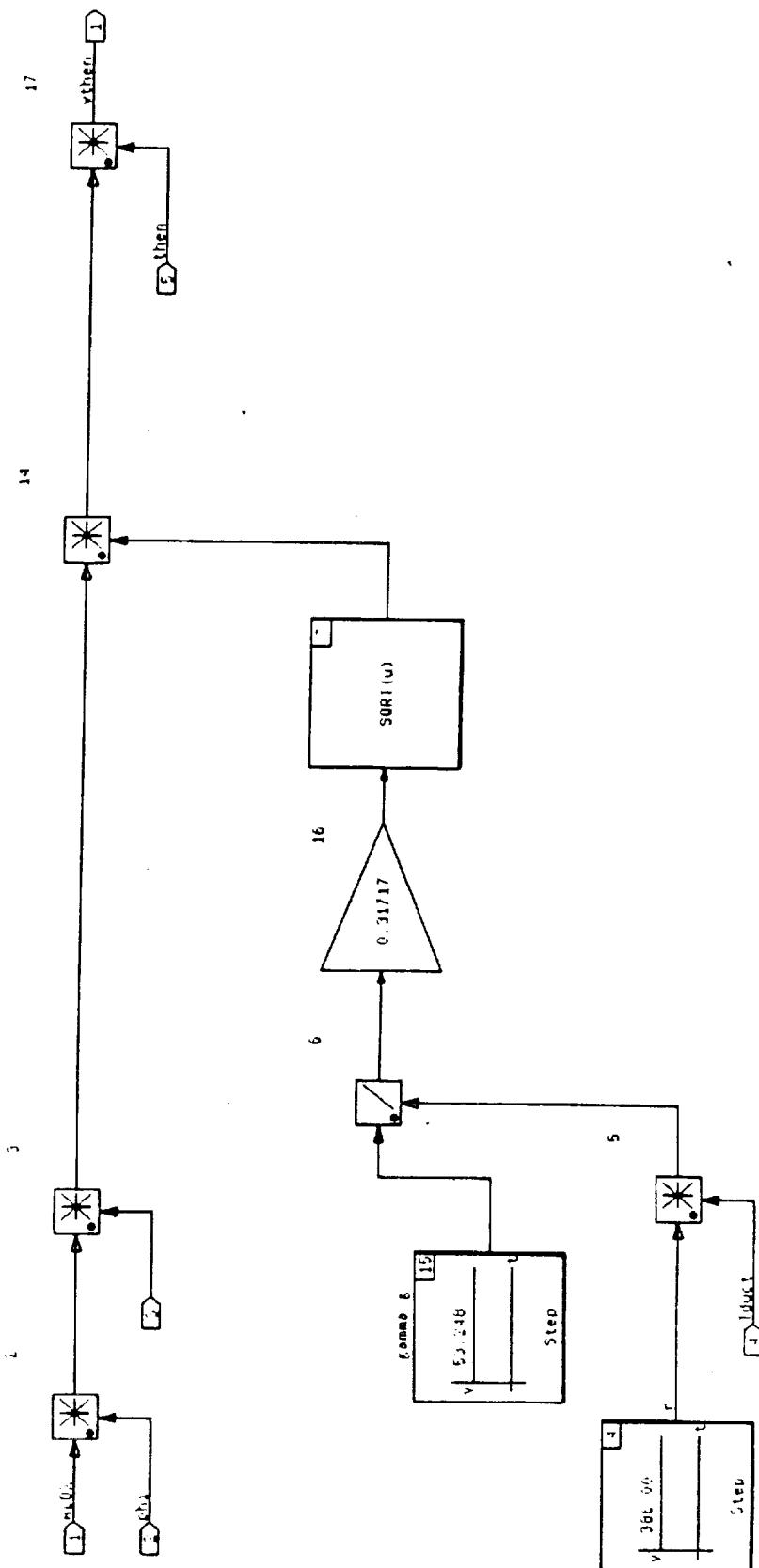
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
 Selection logic 2 5



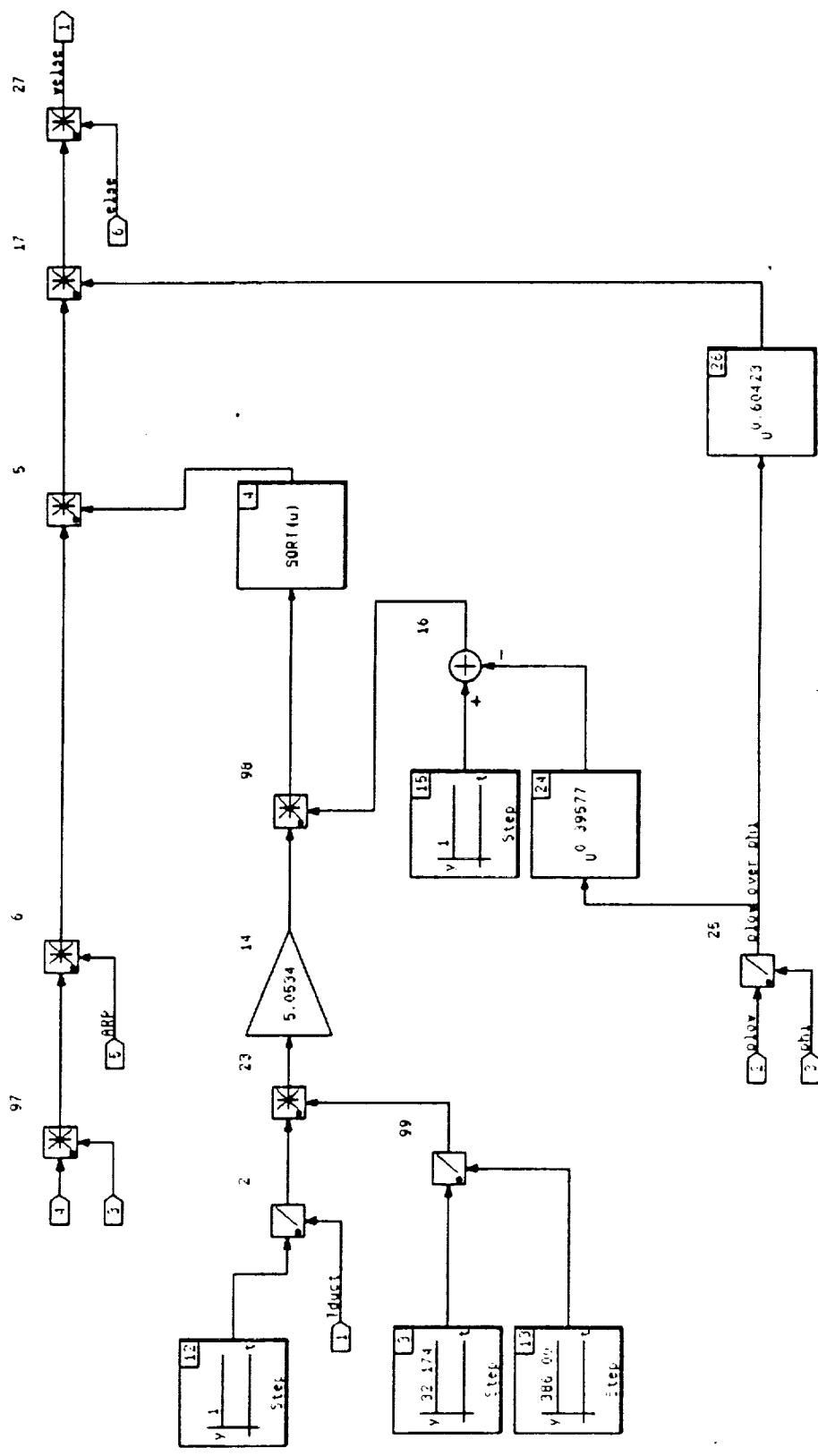
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
when 1 1



HINTS

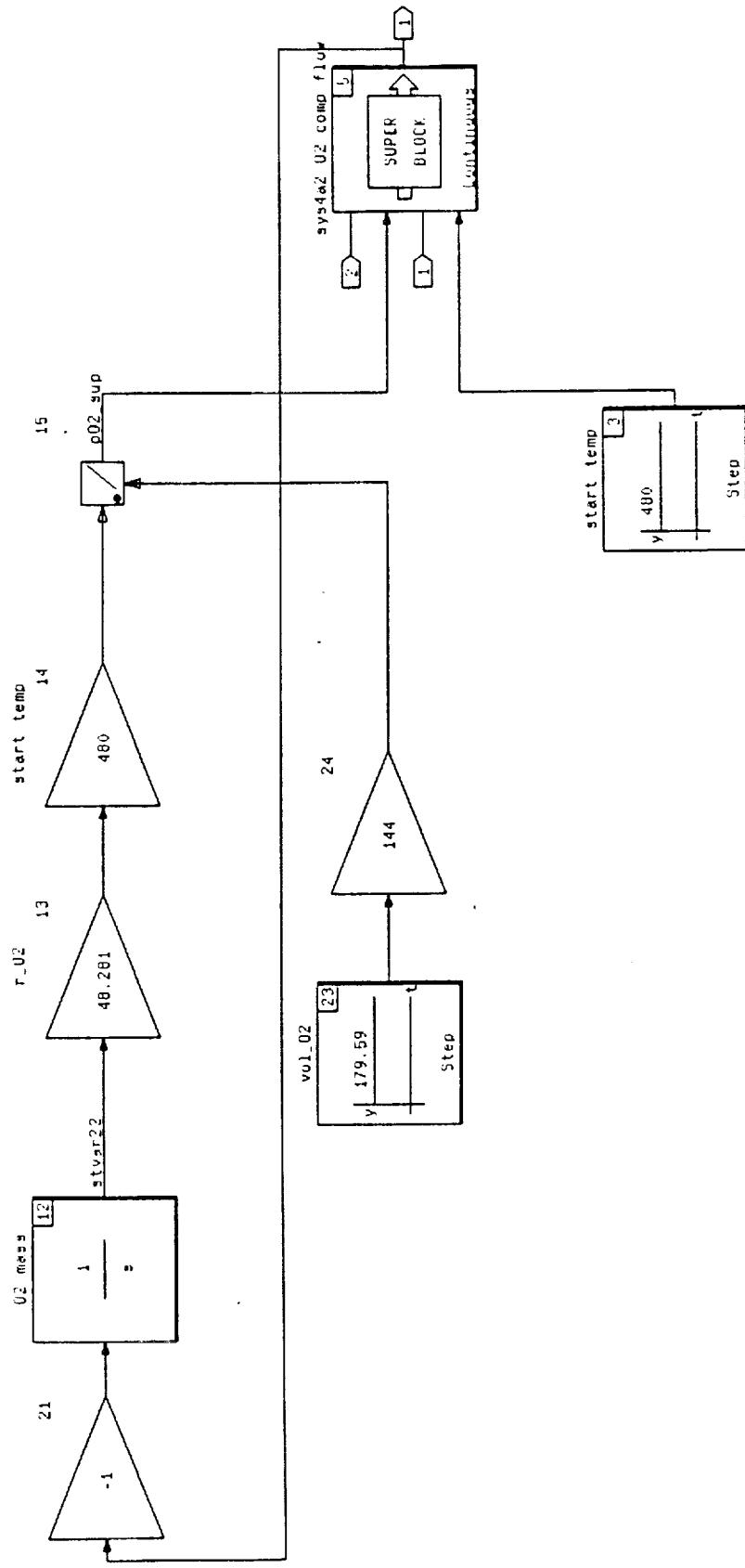
Continuous Super-Block Ext. Inputs Ext. Outputs
welse 1



HINTS

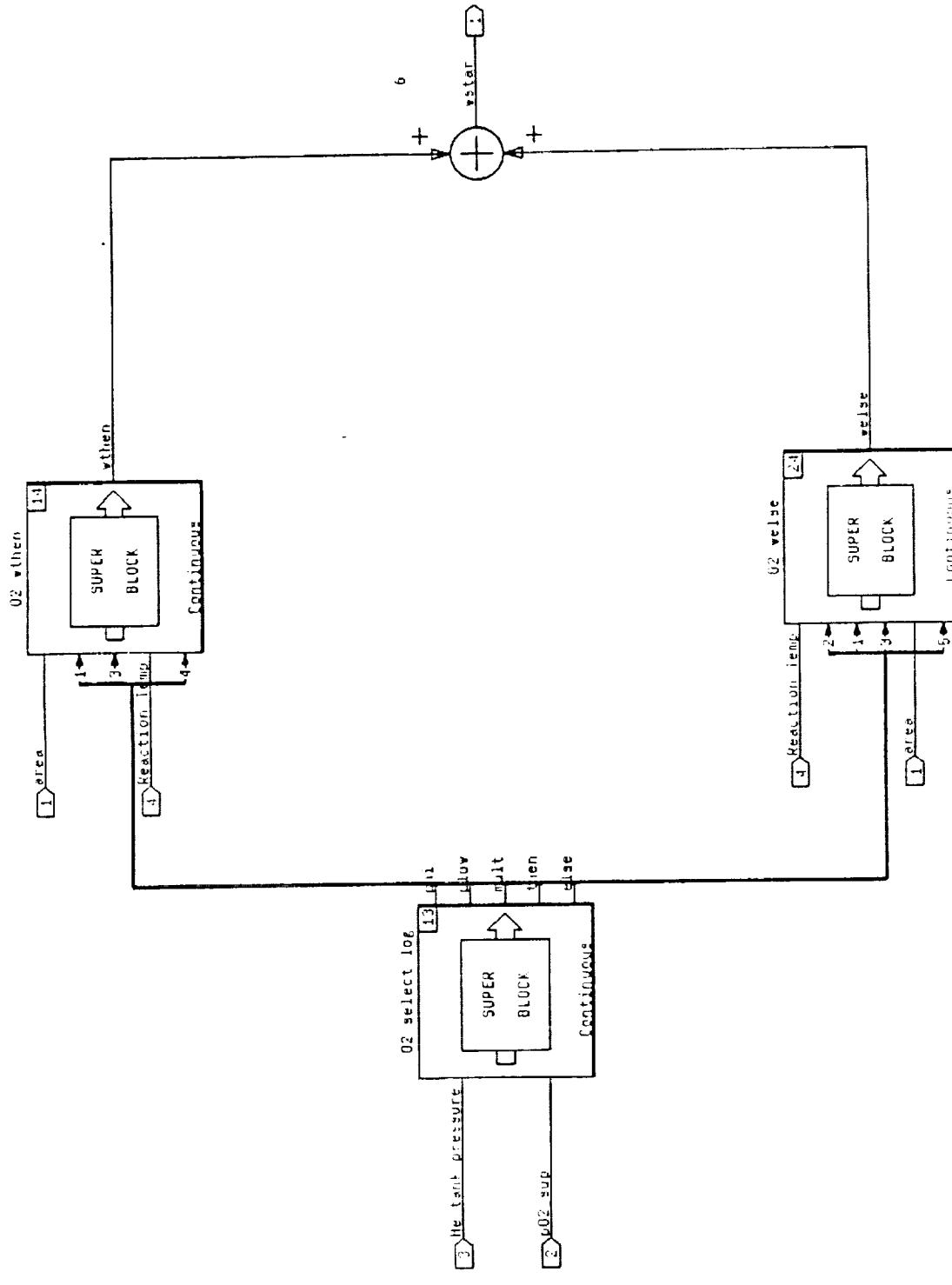
Continuous Super-Block
Sys4a2 Gaseous Ox

Ext. Inputs Ext. Outputs
Z 1



HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
sys4a2 02 comp flow 4 1



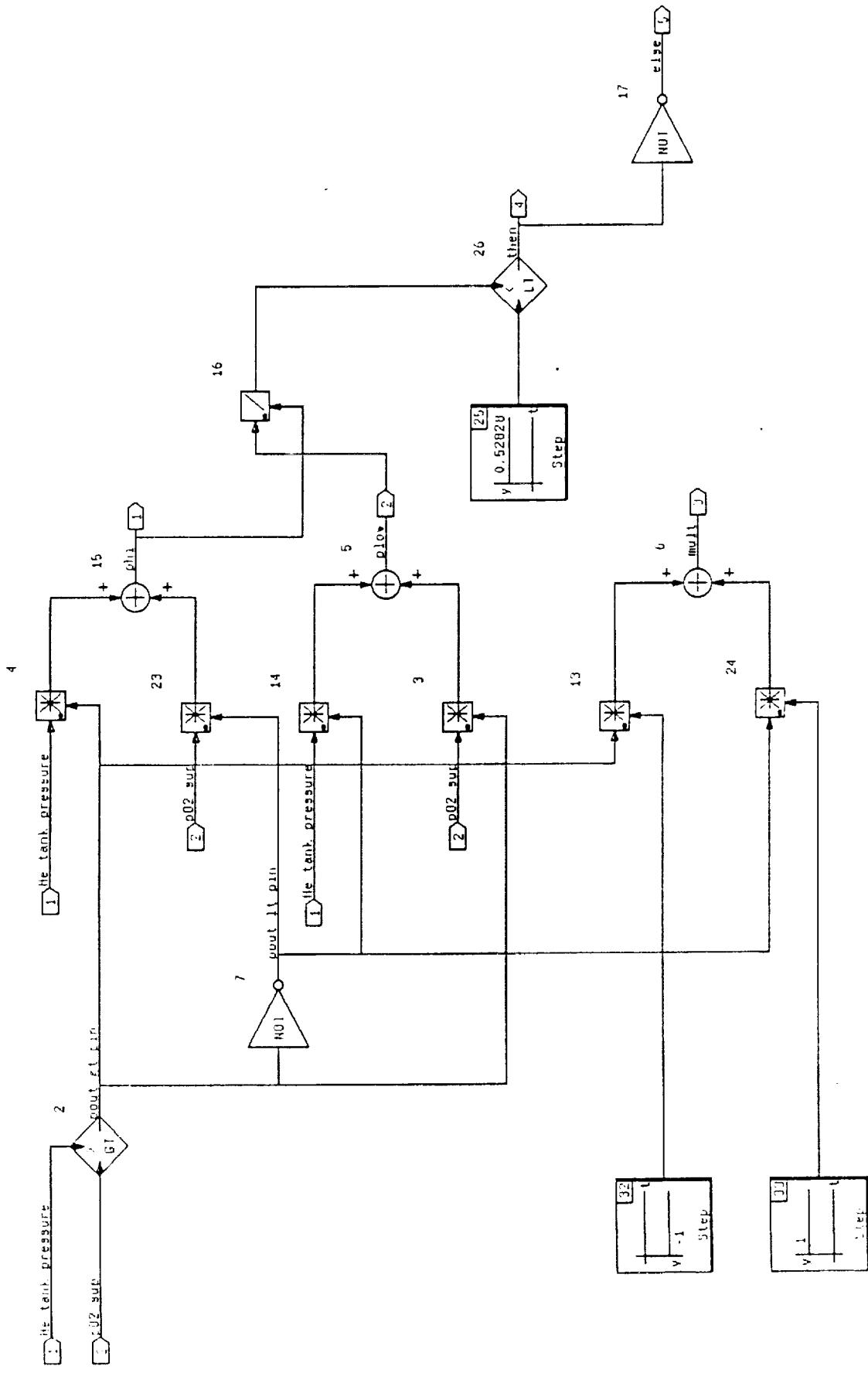
HINTS

Continuous Super-Block
O2 select log

Ext. Inputs Ext. Outputs

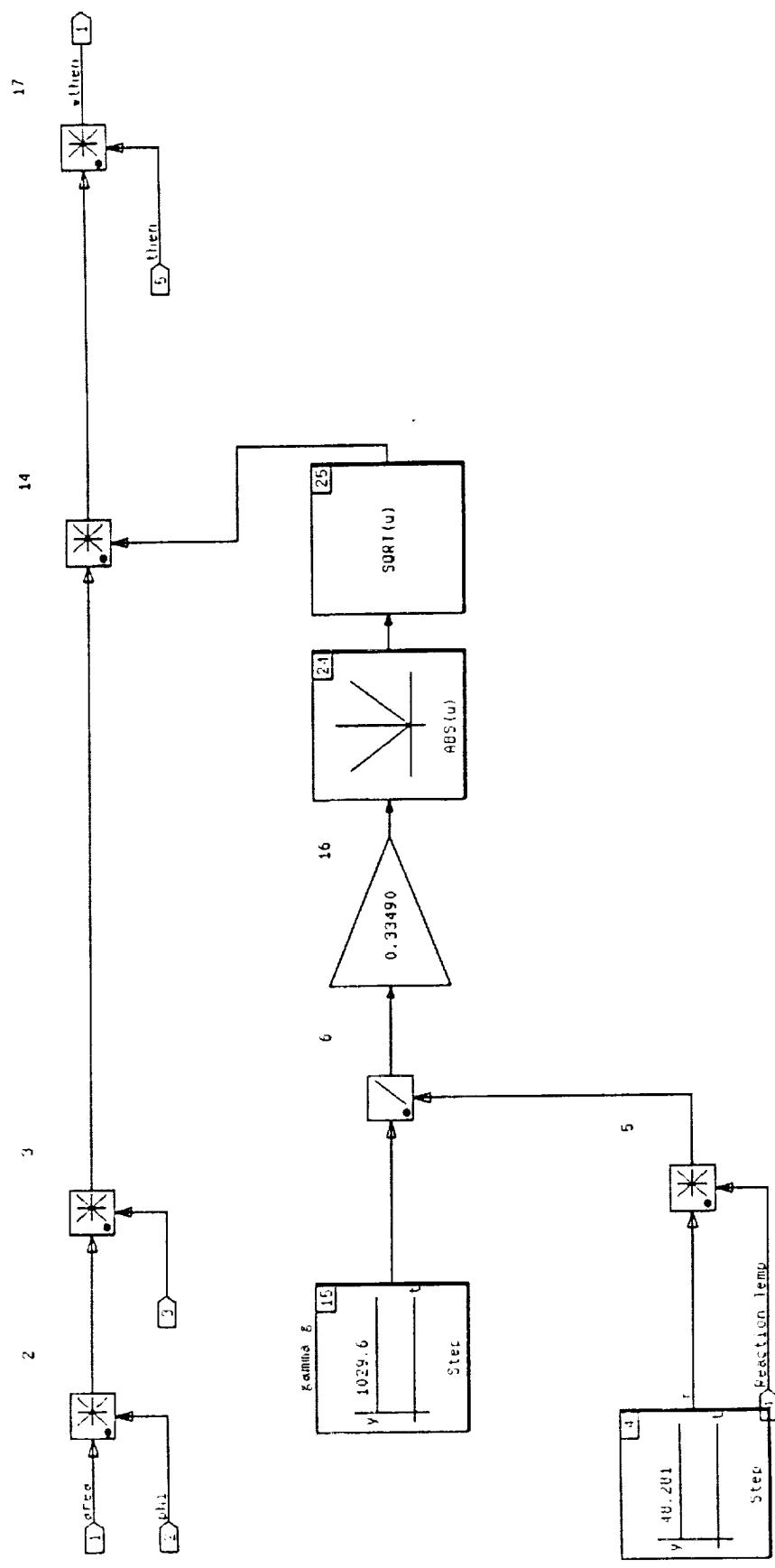
2

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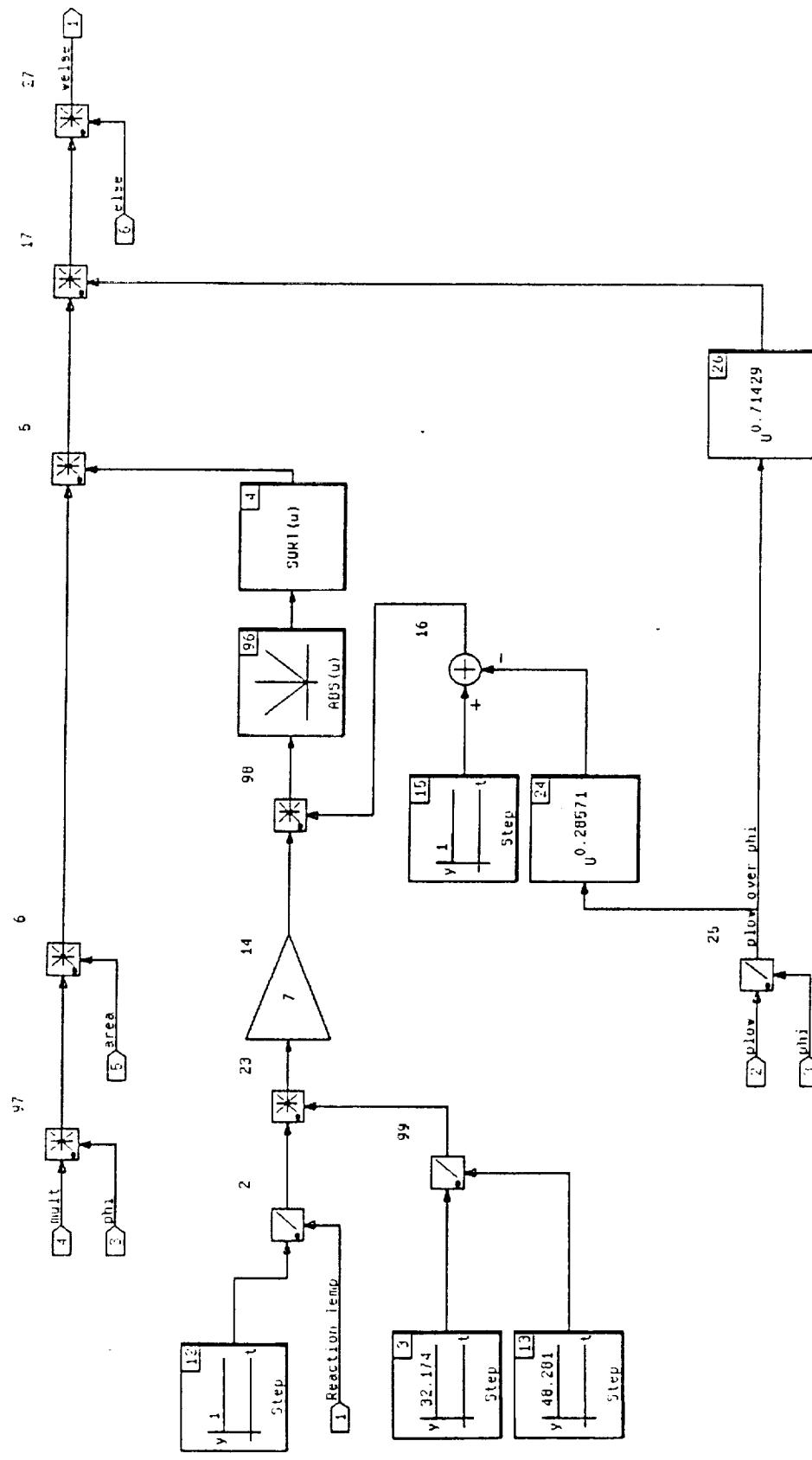
HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
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HINTS

Continuous Super-Block Ext. Inputs Ext. Outputs
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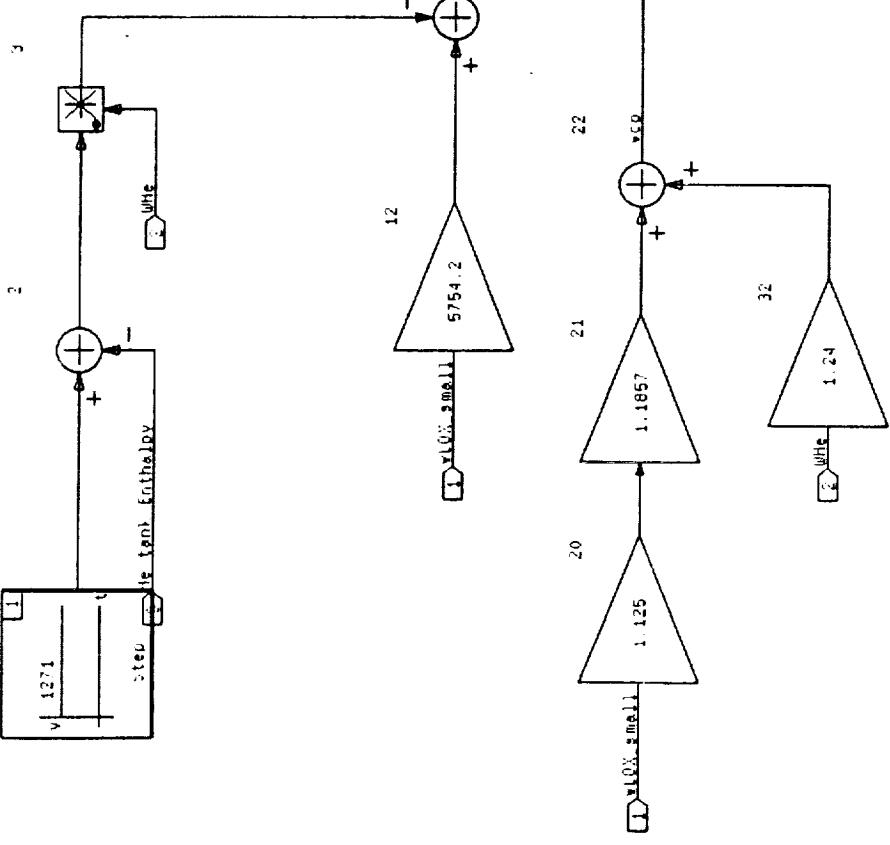
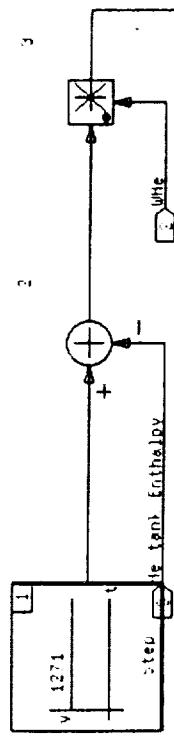


HINTS

Continuous Super-Block
Catalyst Feed

Ext. Inputs Ext. Outputs

1 1

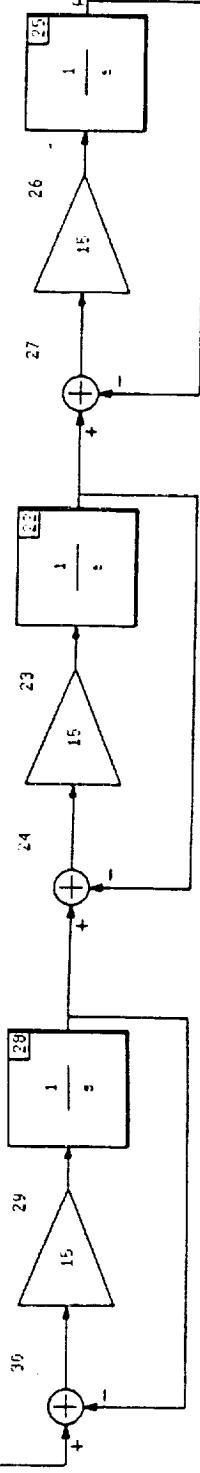
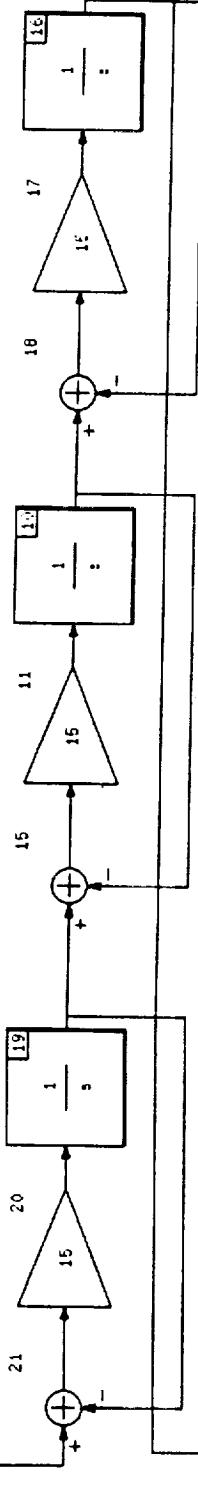
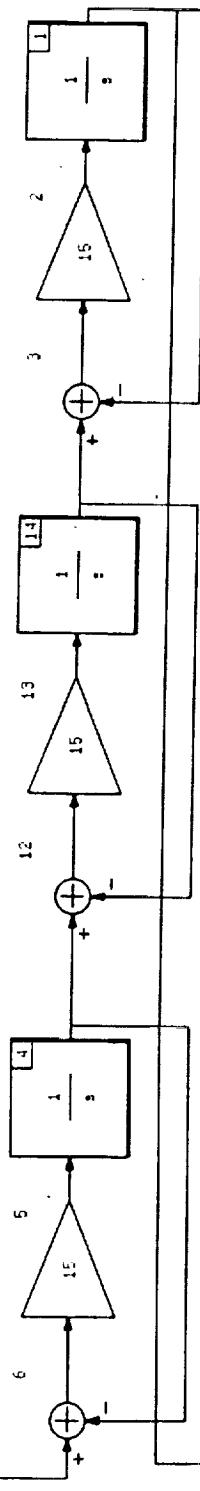
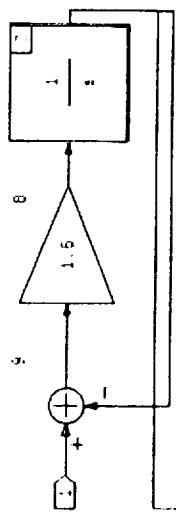


HINTS

Continuous Super-Block
Reaction rate

Ext. Inputs Ext. Outputs

1 1



HINTS

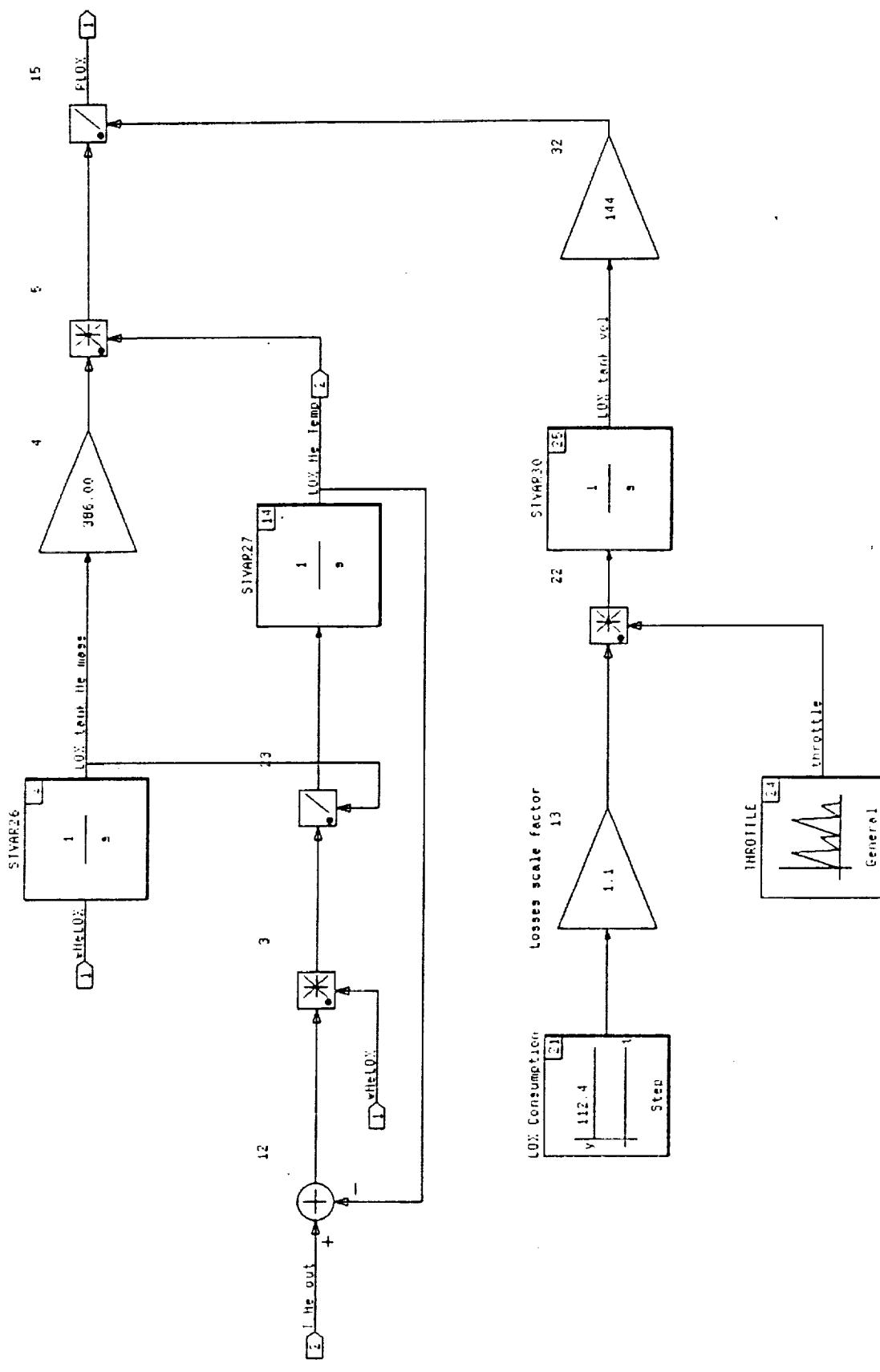
Continuous Super-Block
LHC Tank

Ext. Inputs

2

Ext. Outputs

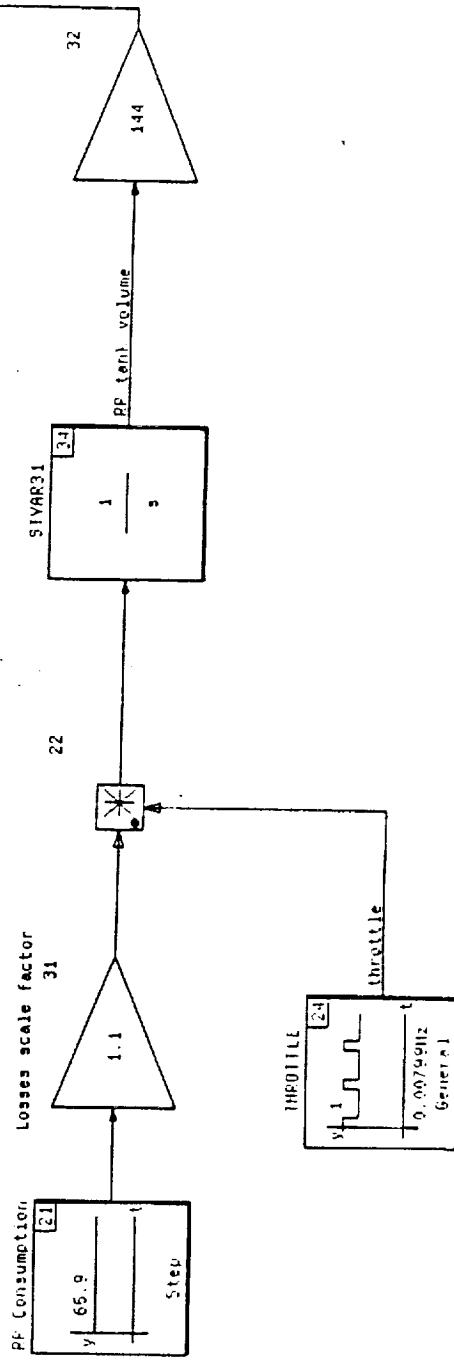
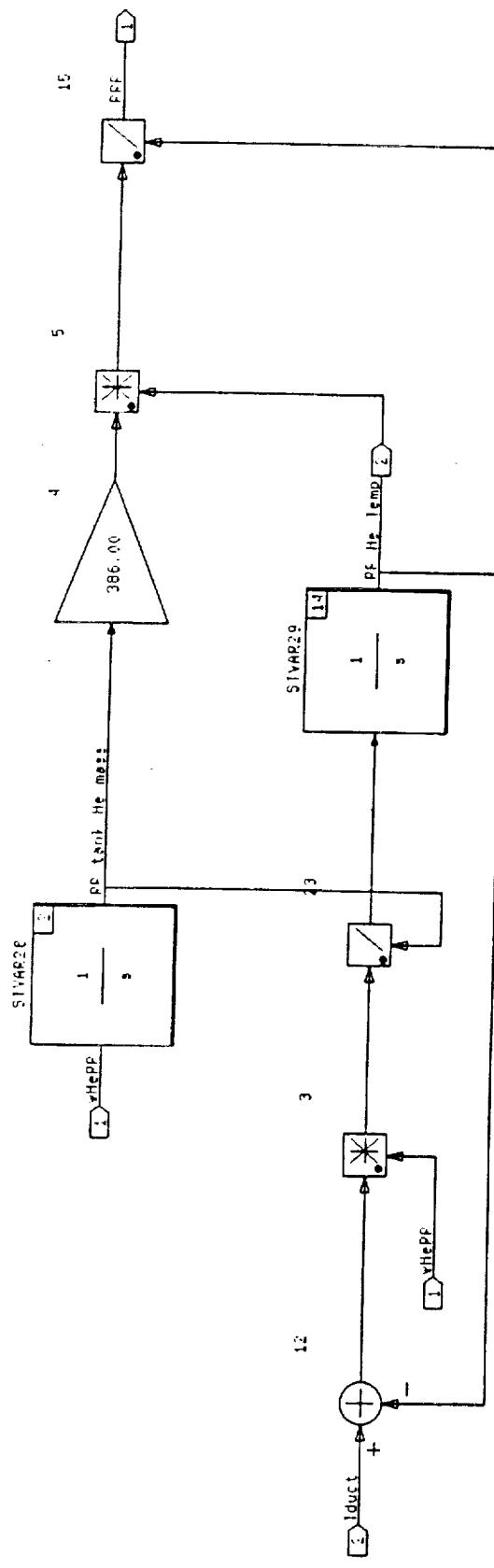
2



HINTS

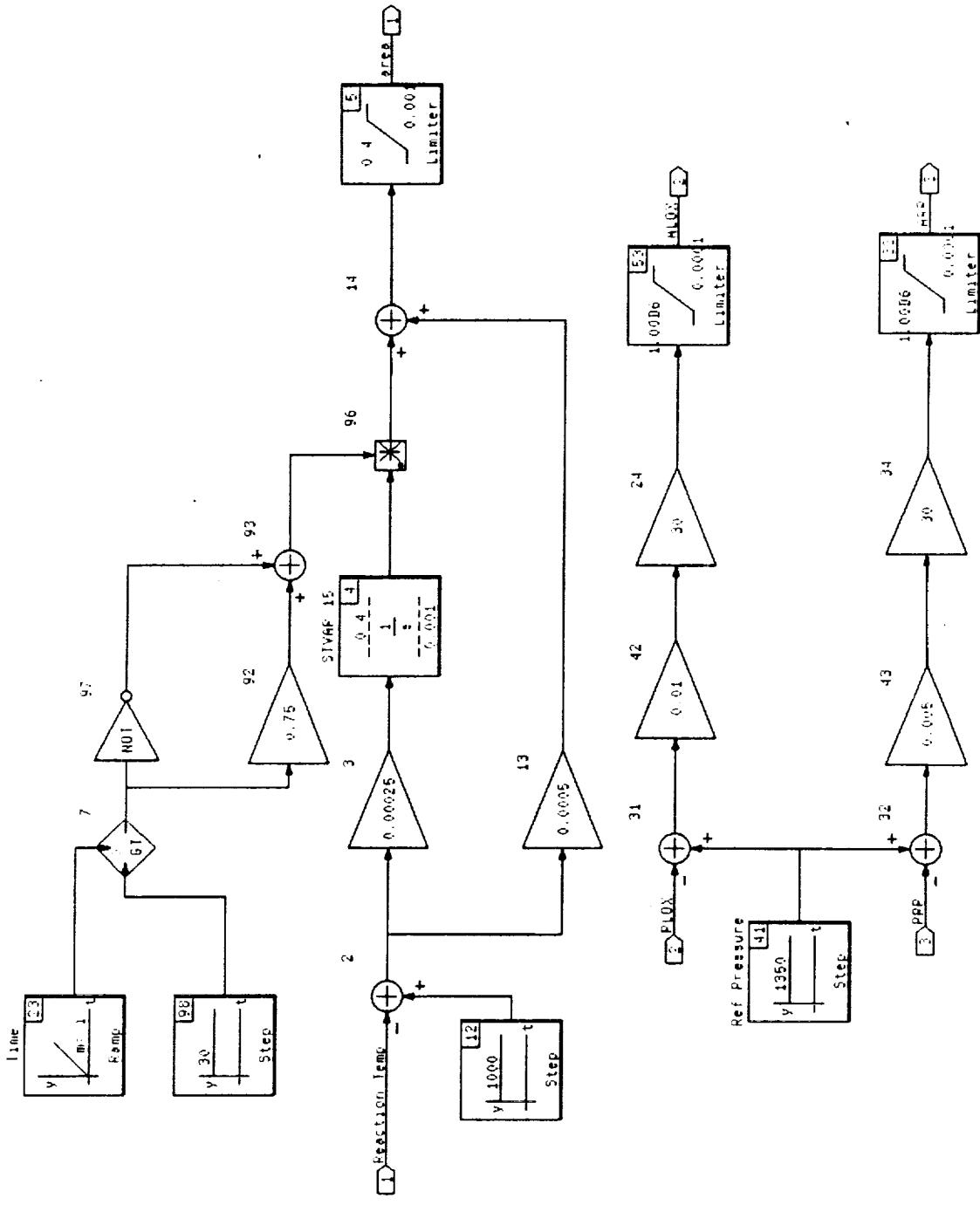
Continuous Super-Block
RF Tank

Ext. Inputs Ext. Outputs



HINTS

Continuous Super-Block Ext. Inputs Ext. Output
 Sys4a2 controller 3 3



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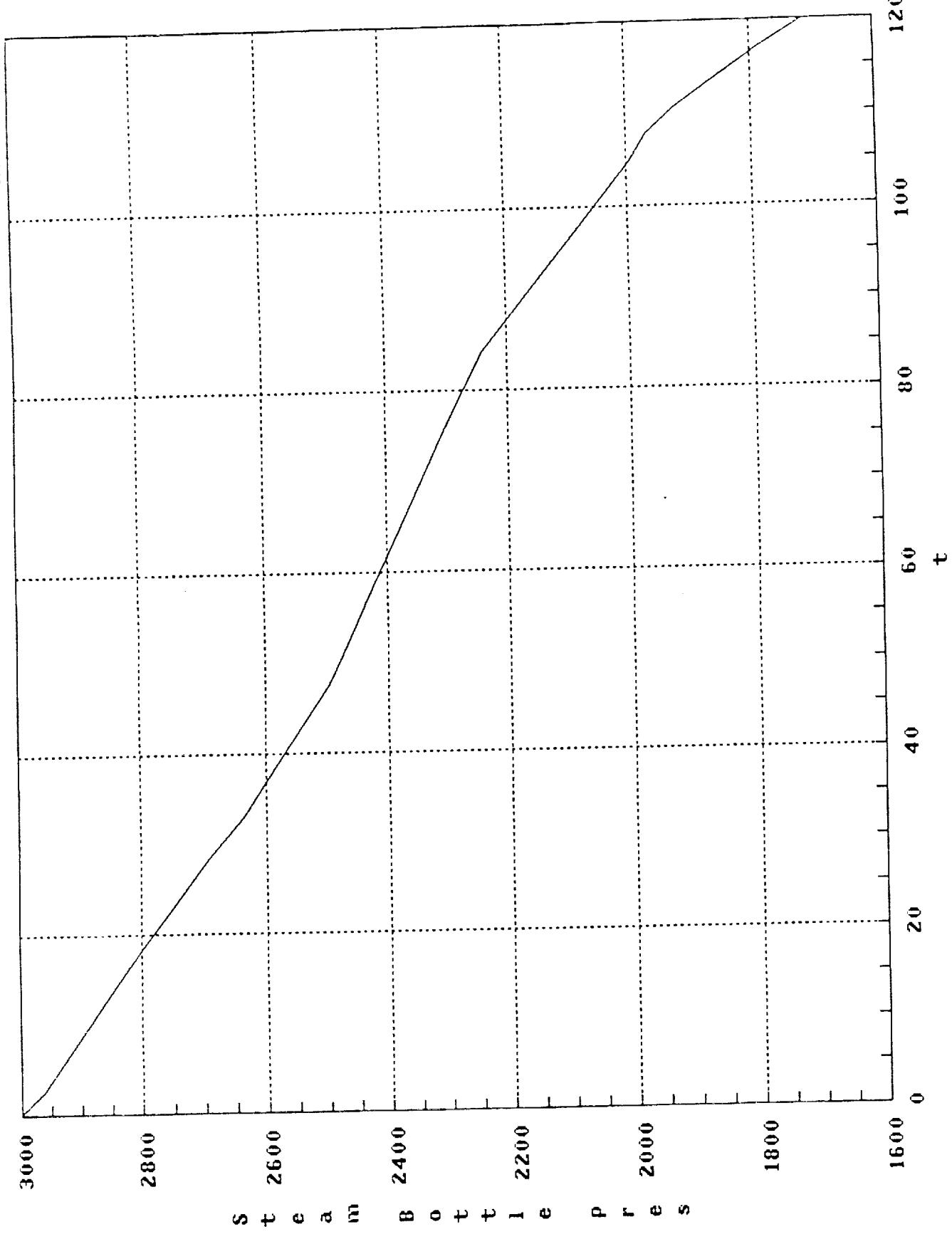
28-FEB-90



CONFIGURATION 402

289

28-FEB-90

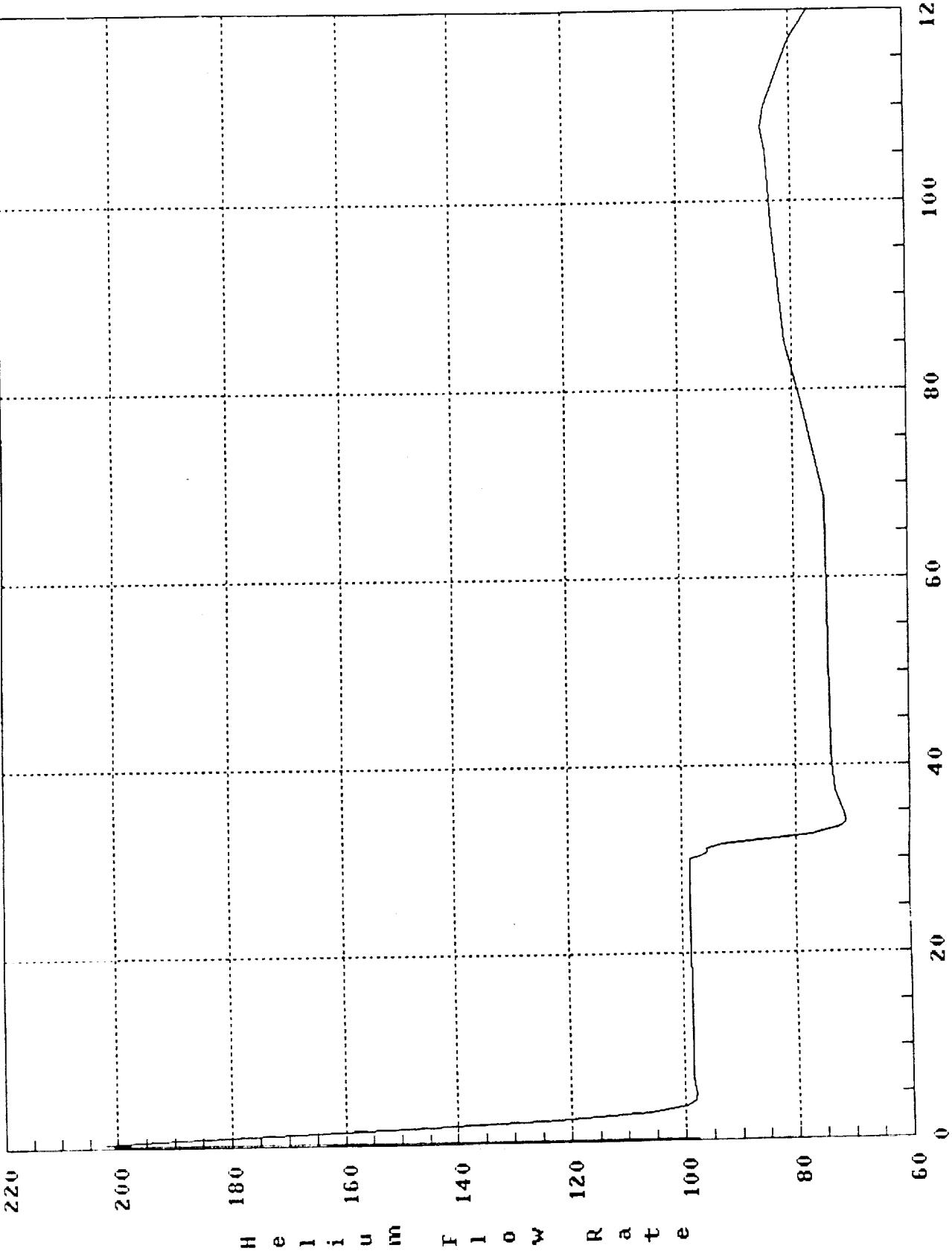


CONFIGURATION 4a2

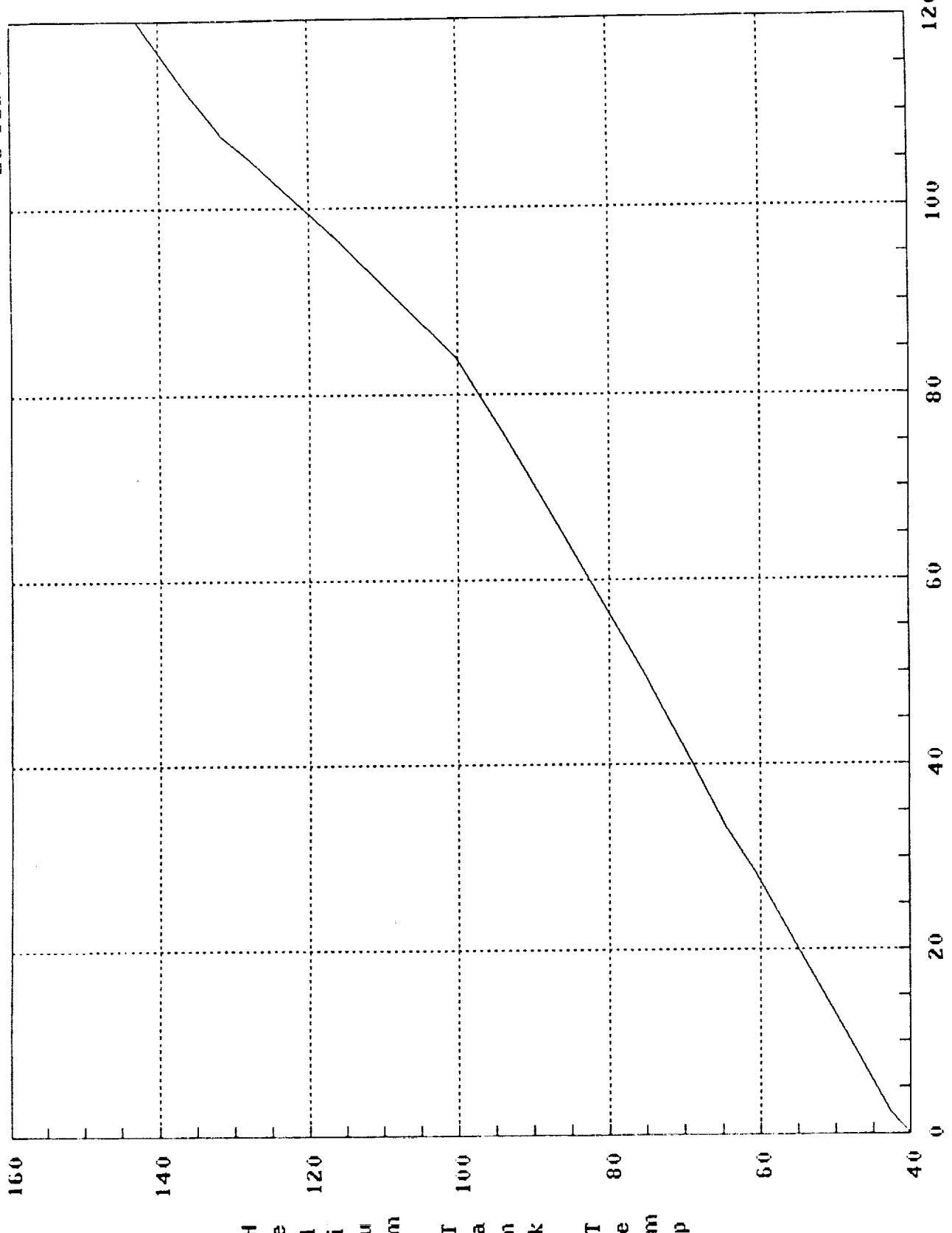
290

C-4

28-FEB-90

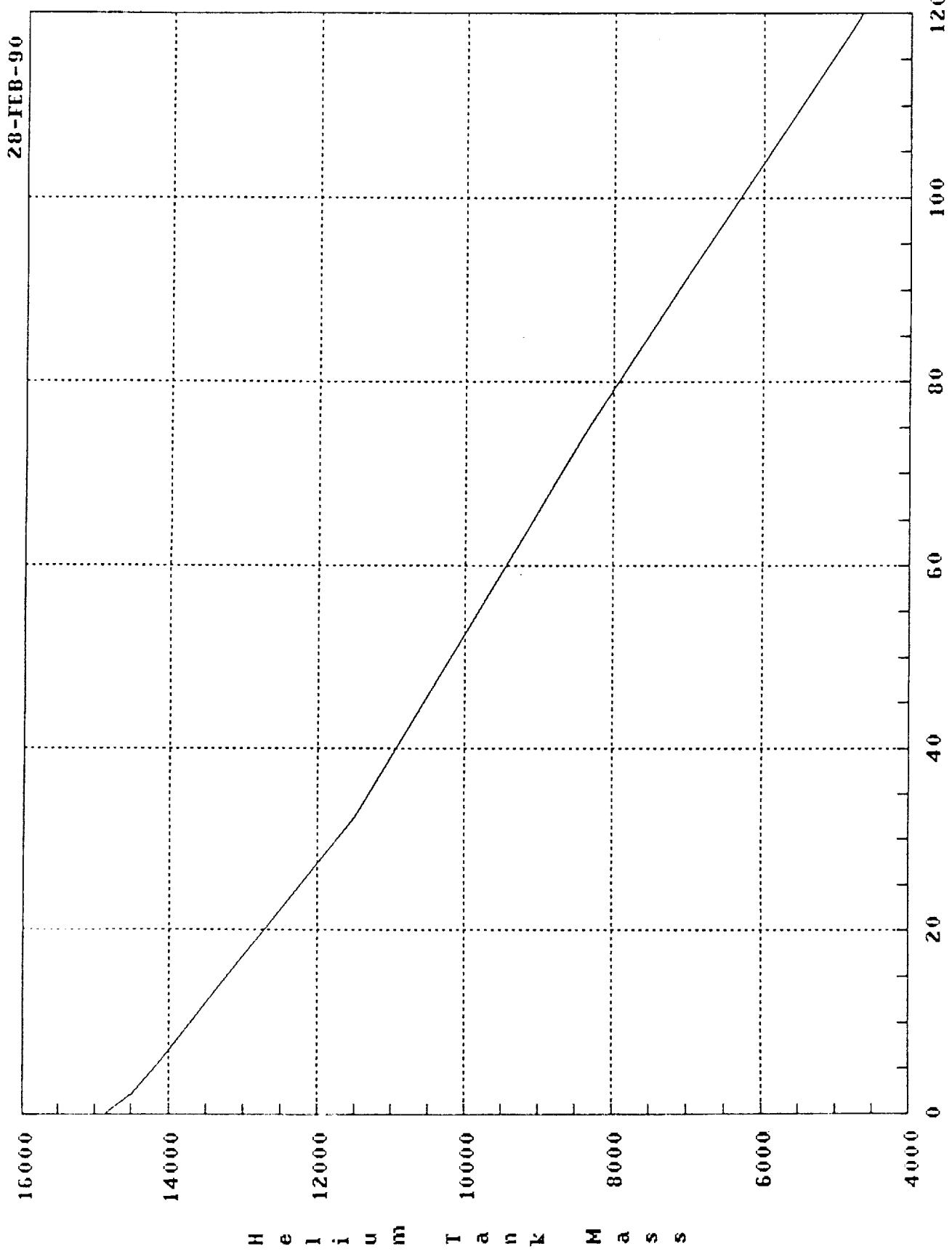


CONFIGURATION 4a2



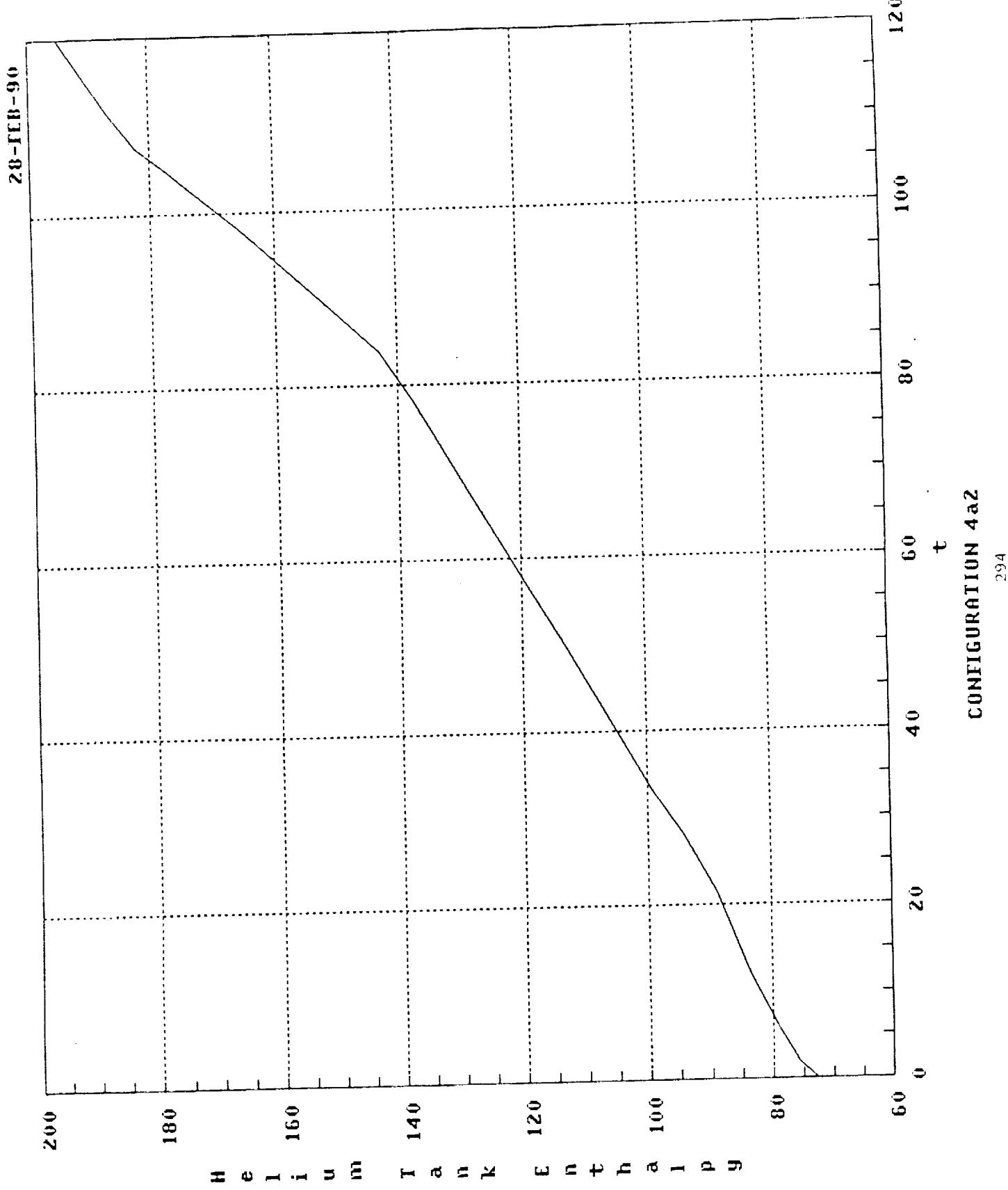
H e i u m T a n k T e m p

28-FEB-96

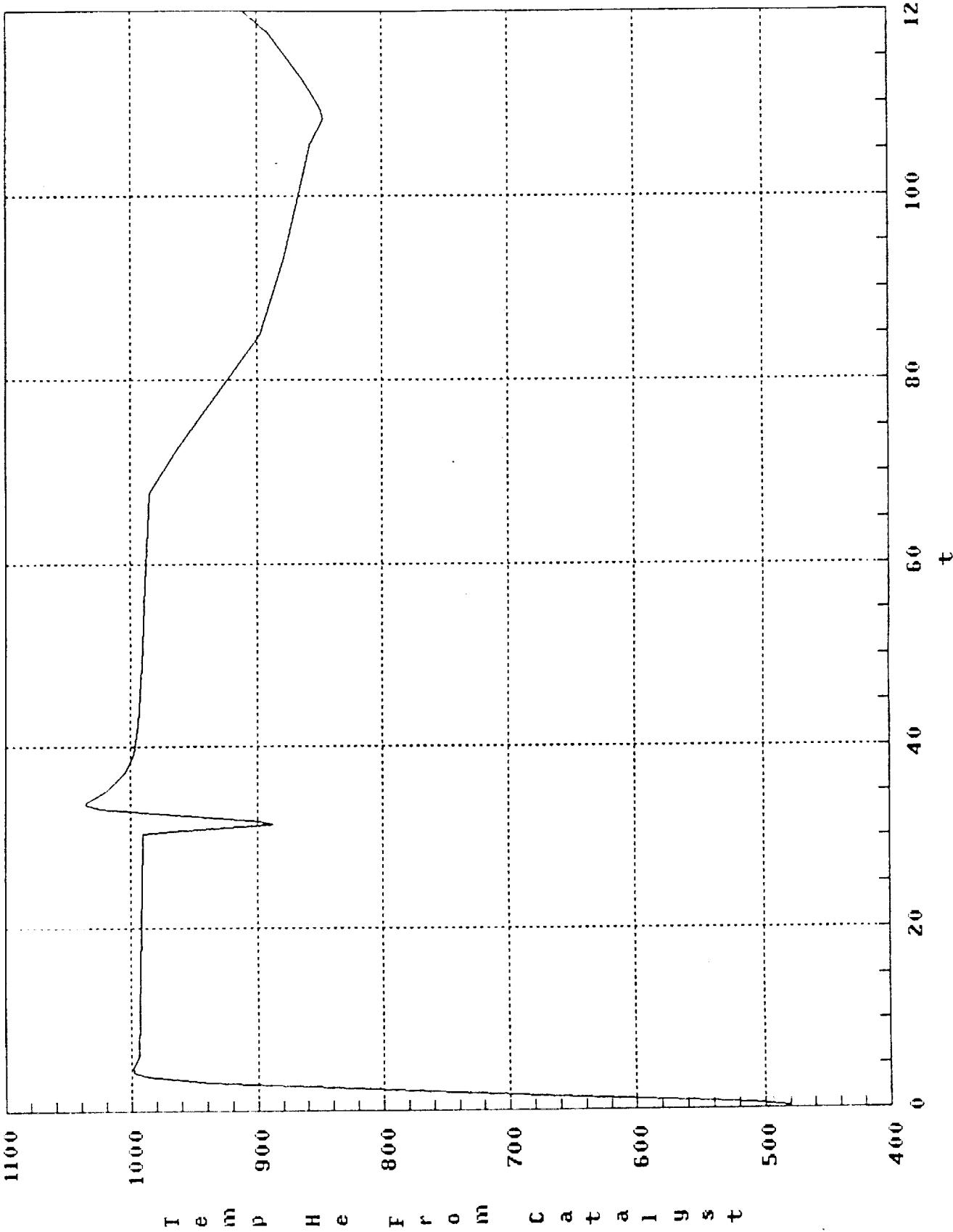


H e i u m T a n k M a s s

CONFIGURATION 4a2
293

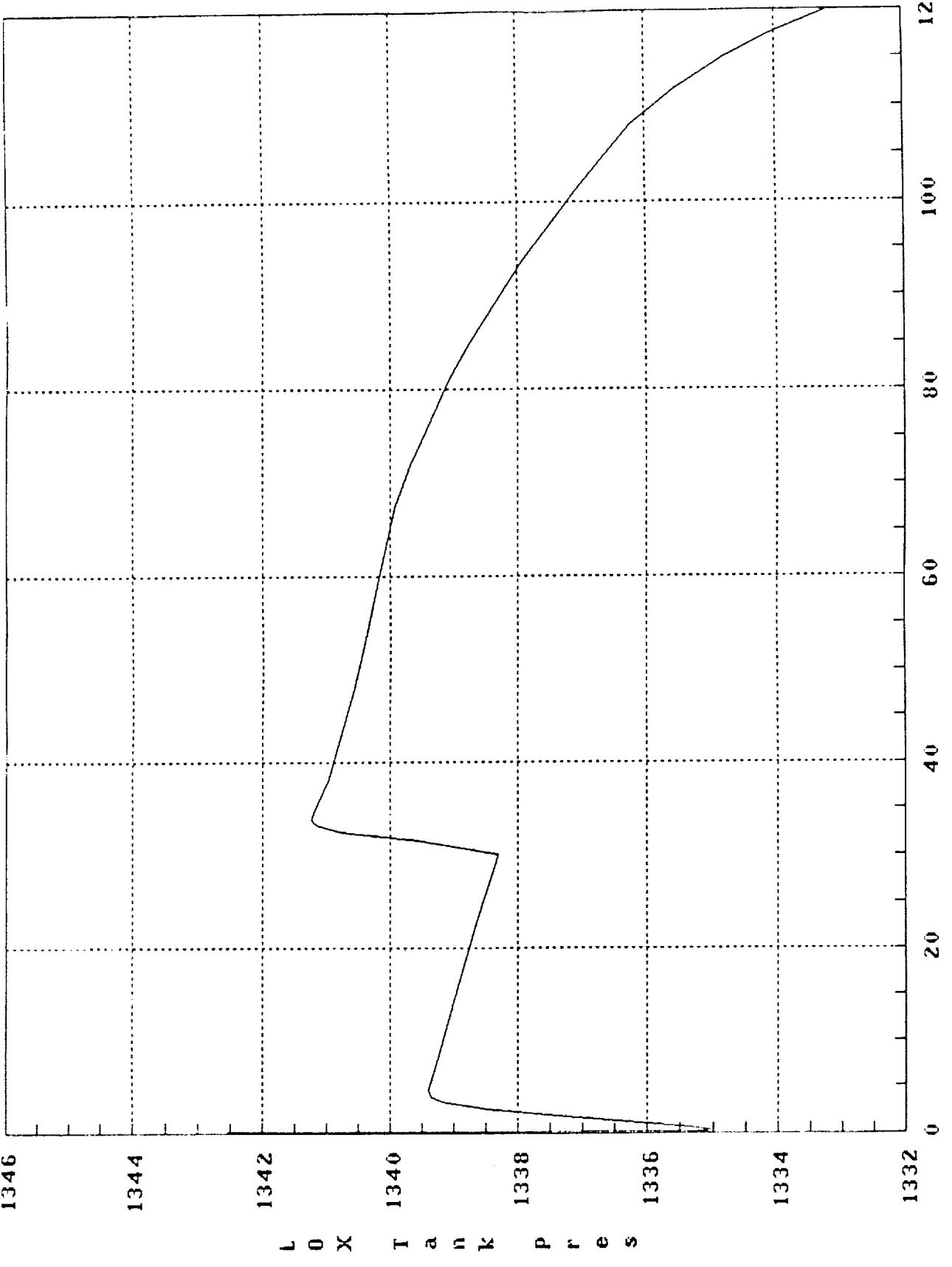


28-FEB-90



CONFIGURATION 4a2

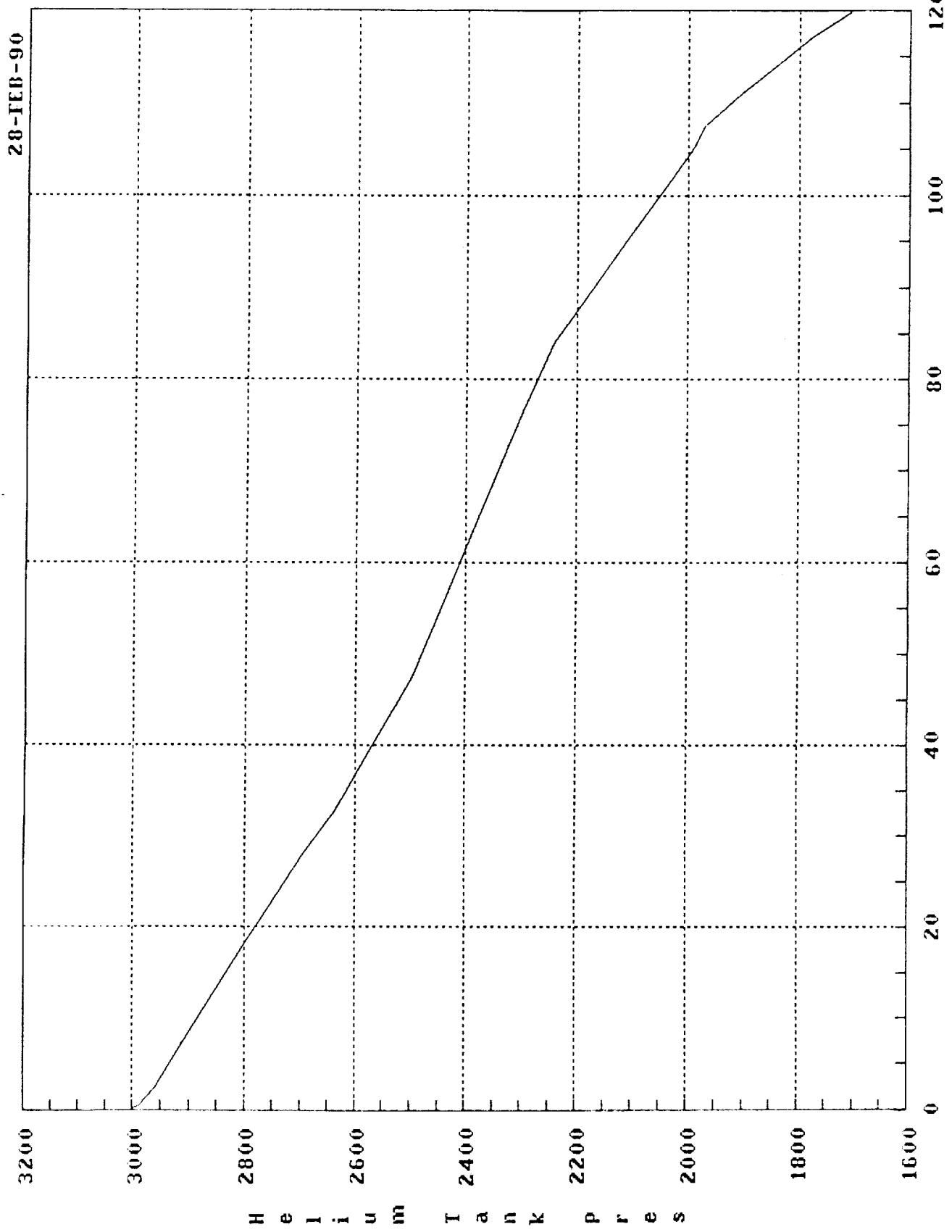
28-ILB-90



CONFIGURATION 4a2

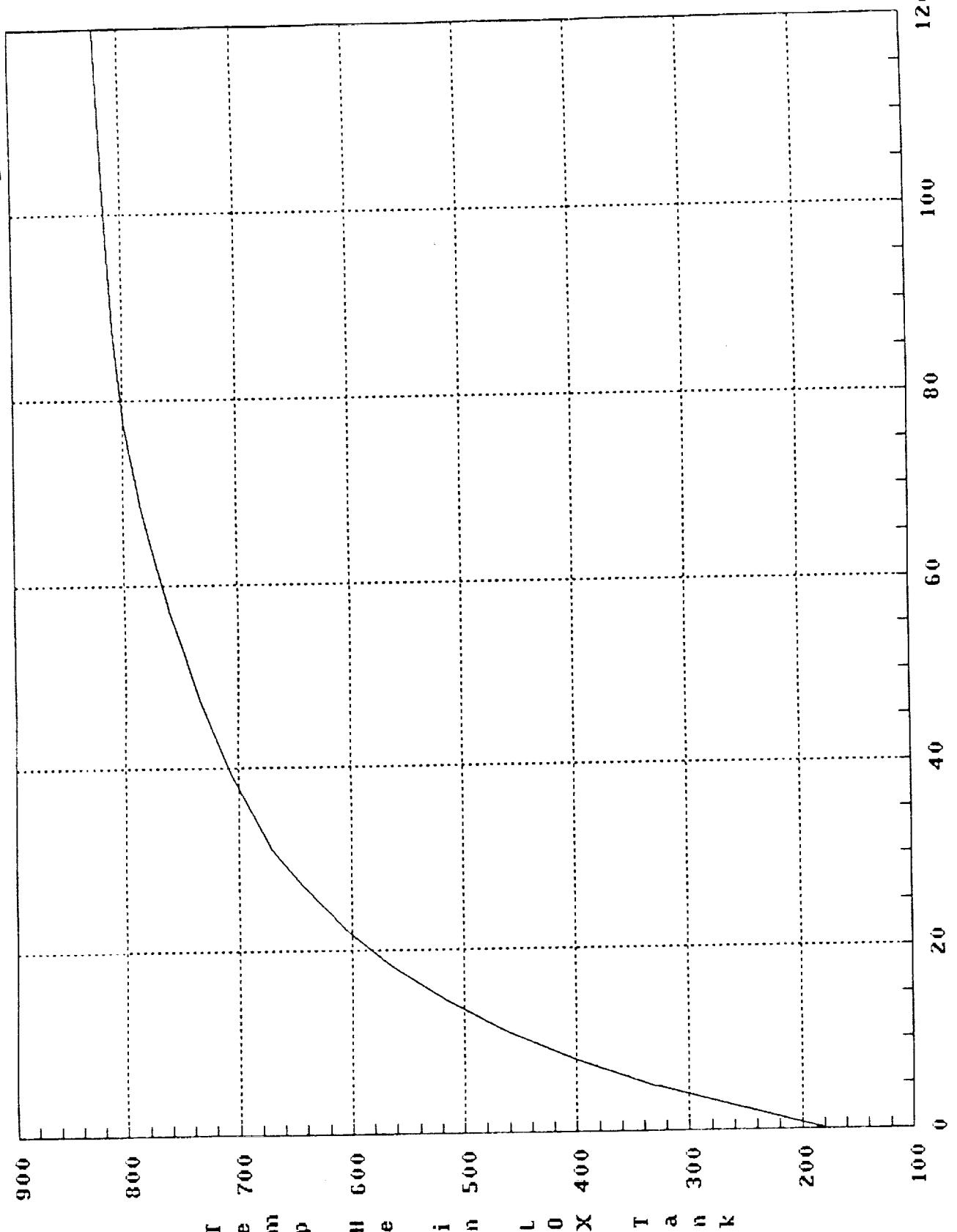
296

28-FEB-90



CONFIGURATION 4a2

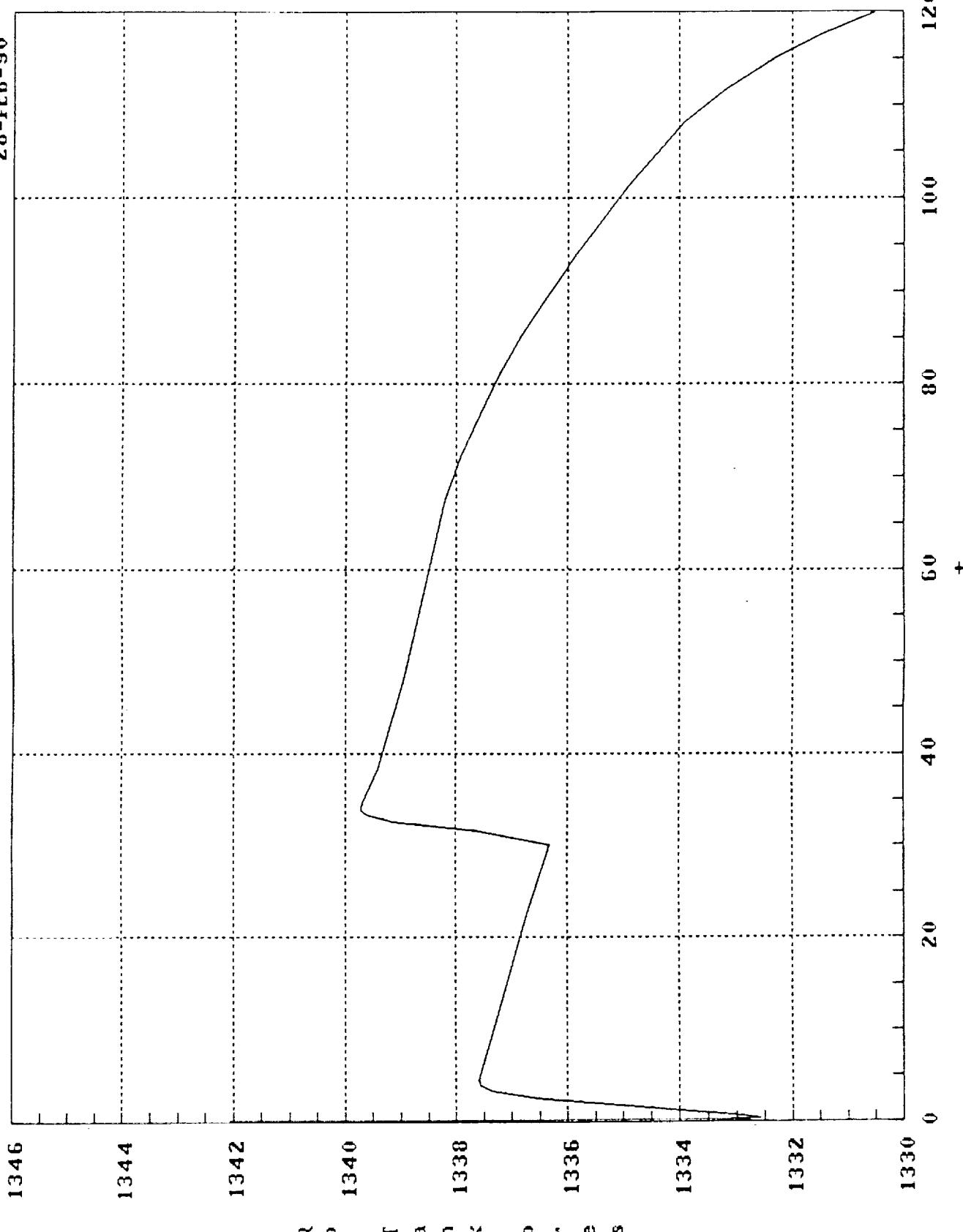
2B-FUB-90



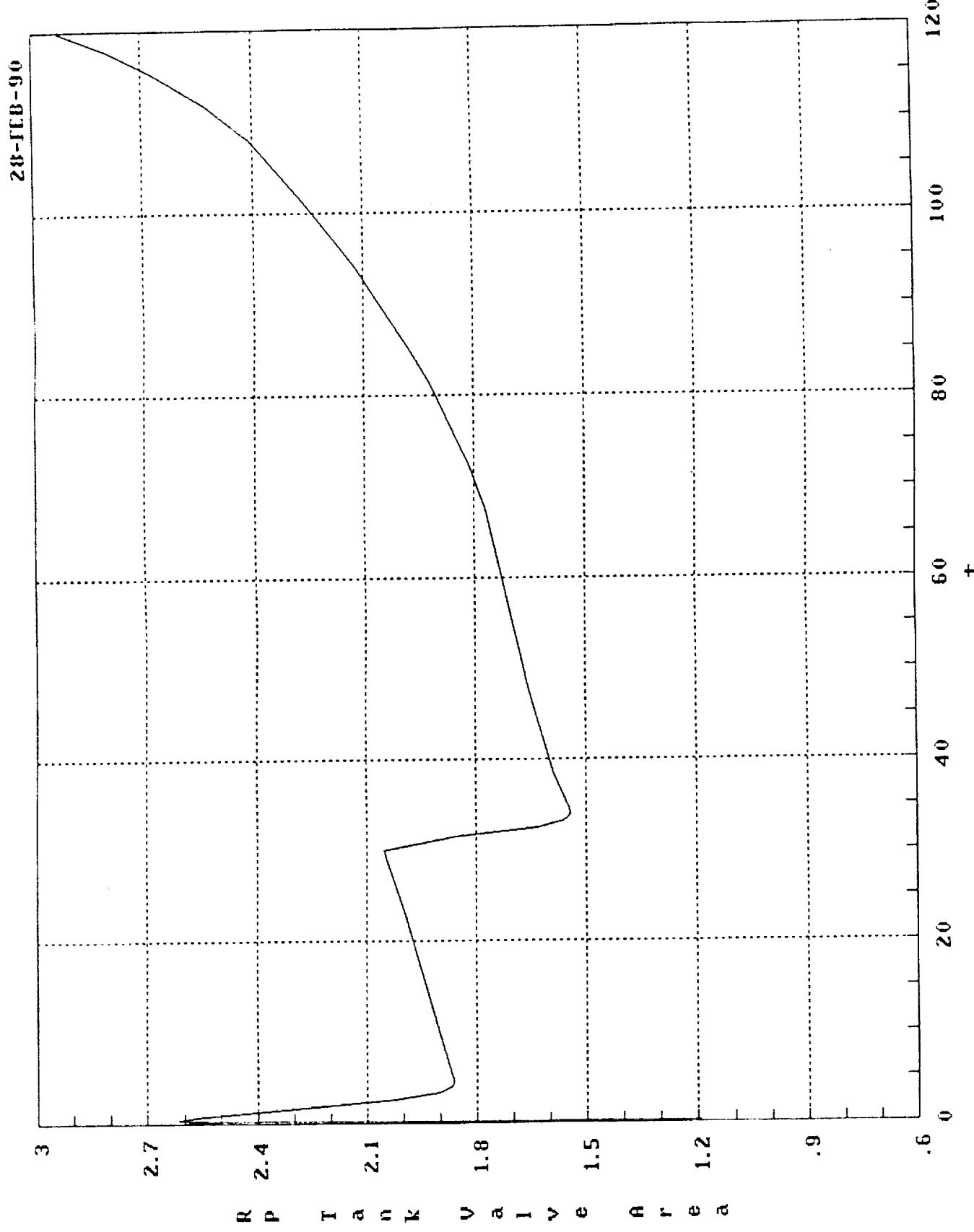
CONFIGURATION 4a2

298

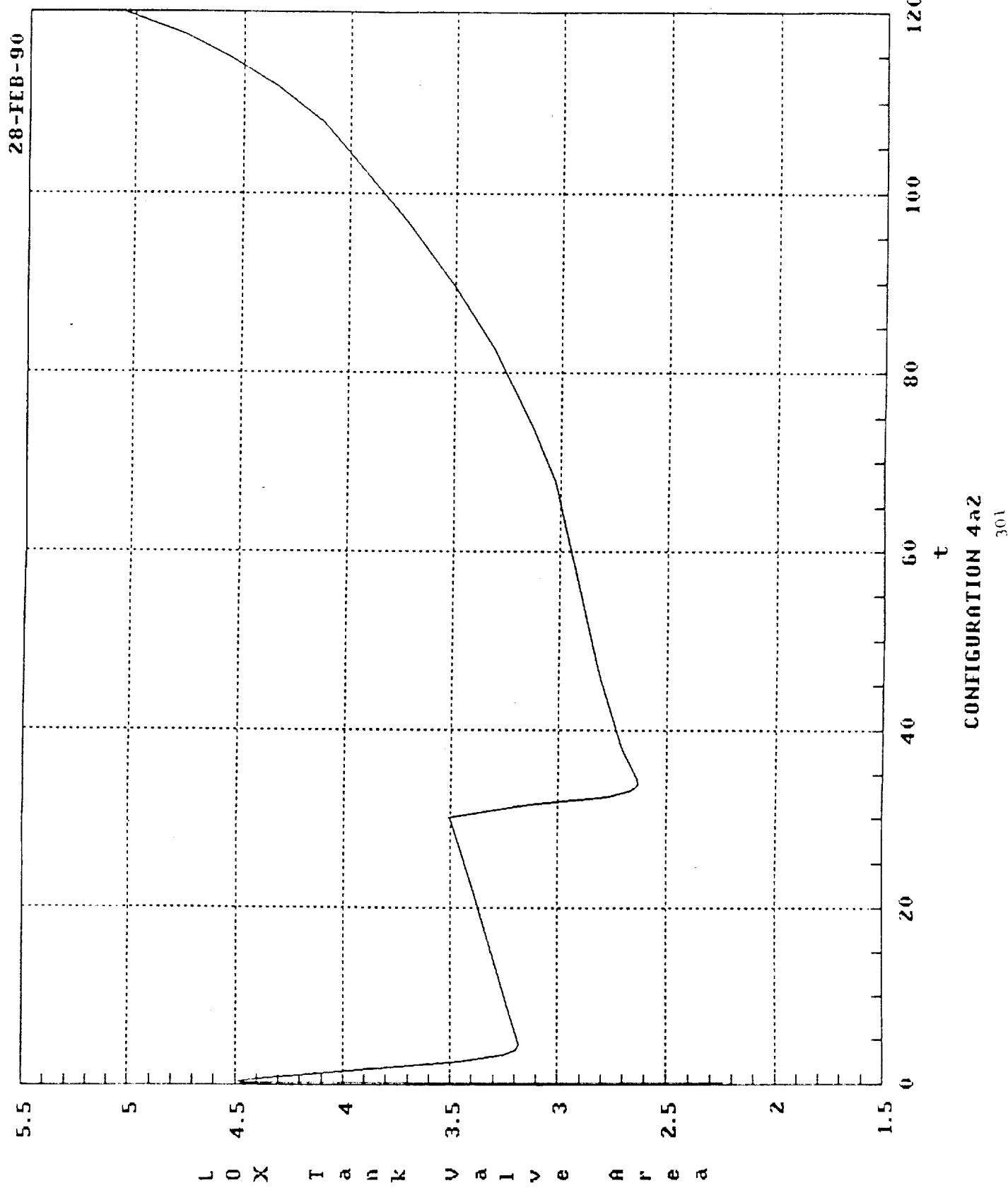
28-FEB-90



CONFIGURATION 4a2

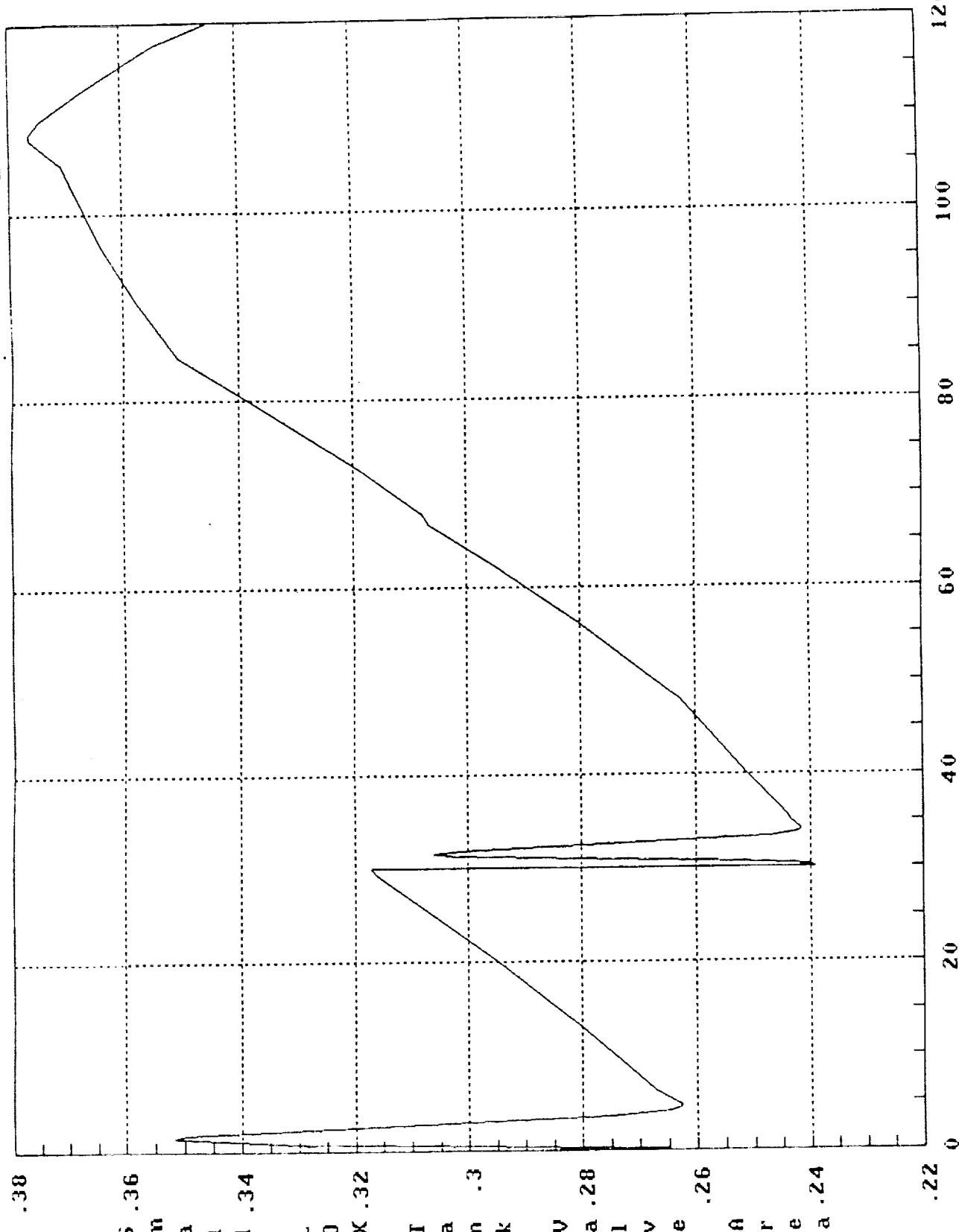


CONFIGURATION 4a2
300



CONFIGURATION 4a2
301

28-FLB-96



CONFIGURATION 4a2

302

32

G a s e o u s T a n M a s s F r a t e

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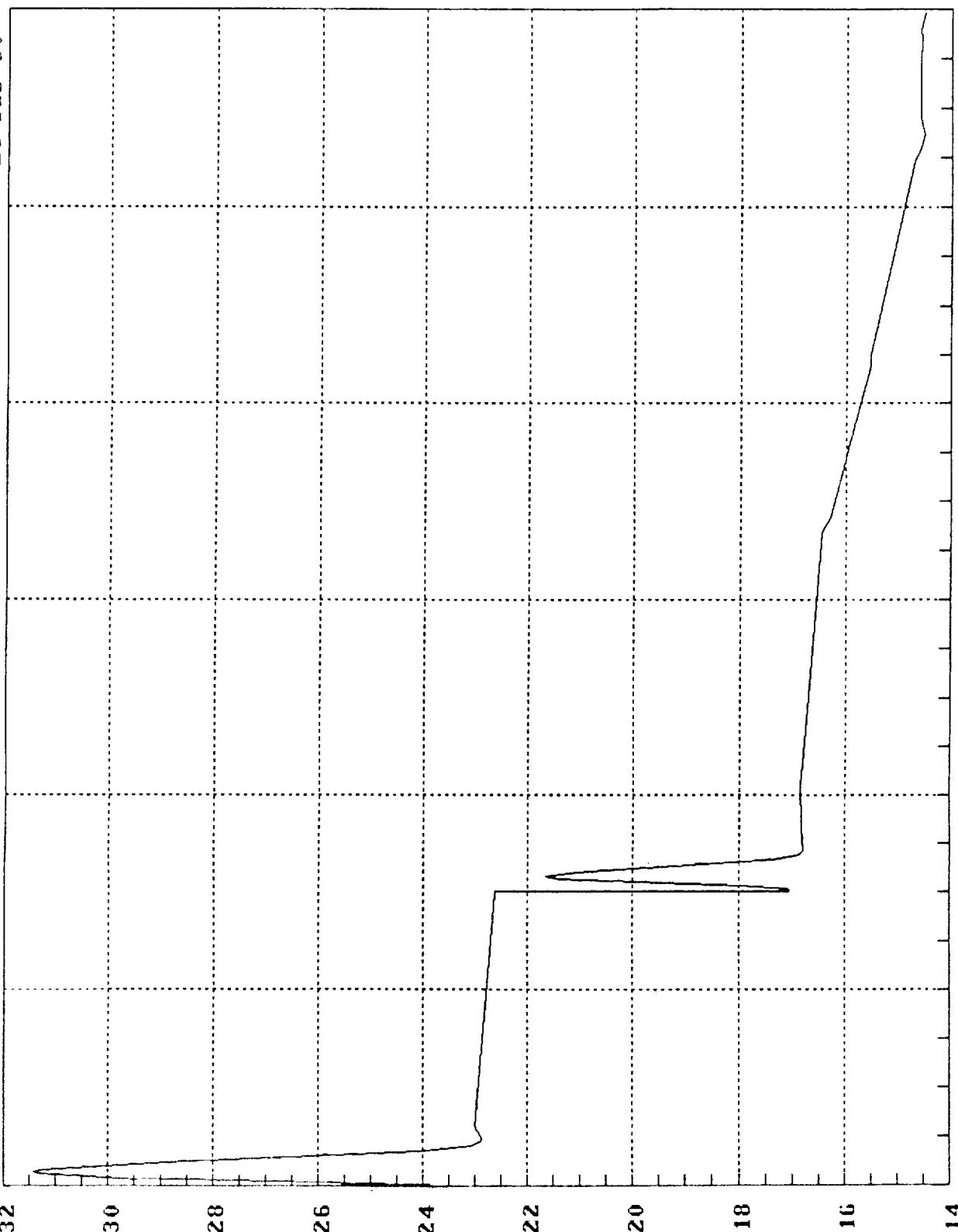
14

28-FEB-90

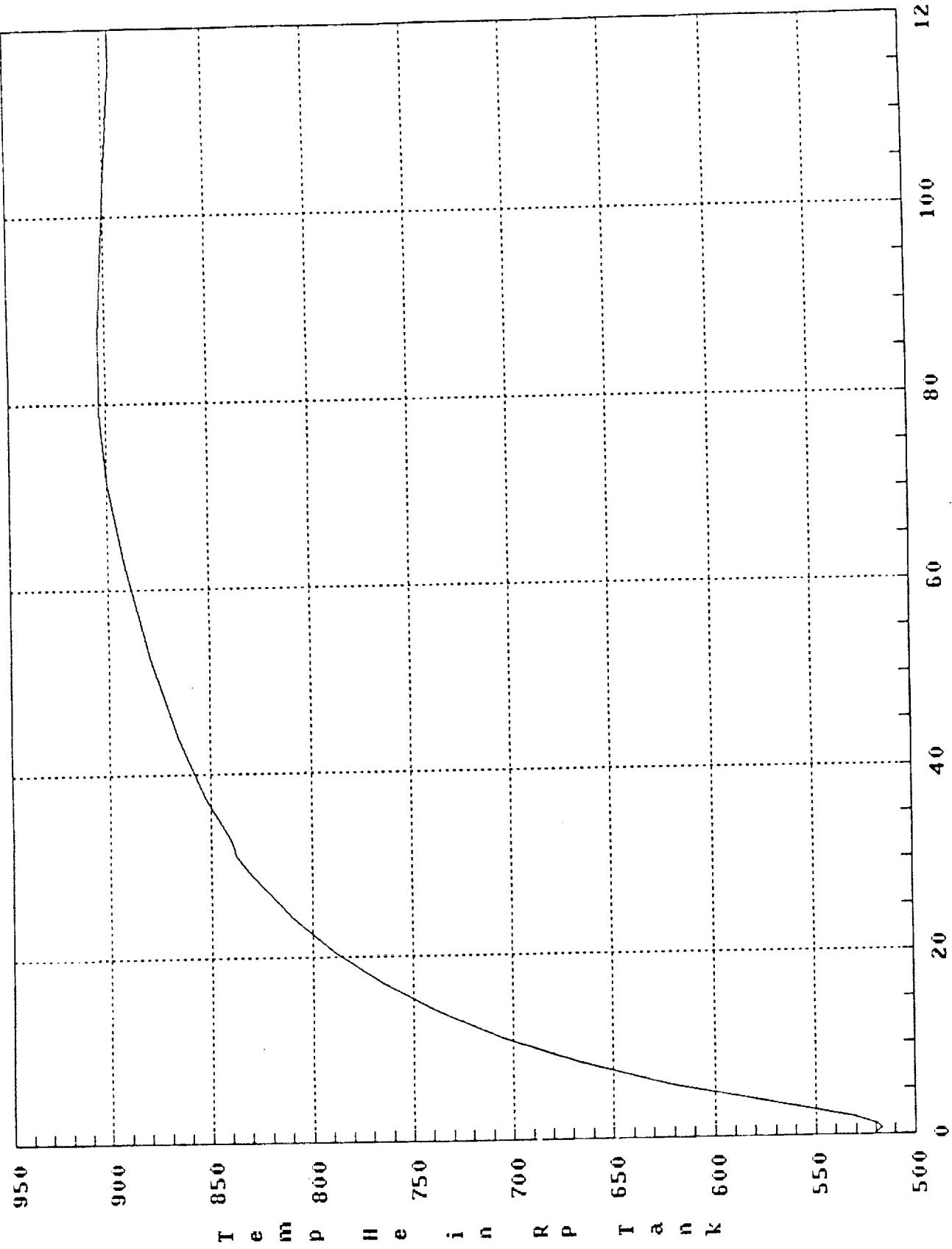
CONFIGURATION 4a2

303

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28-ITB-90



CONFIGURATION 4a2

304

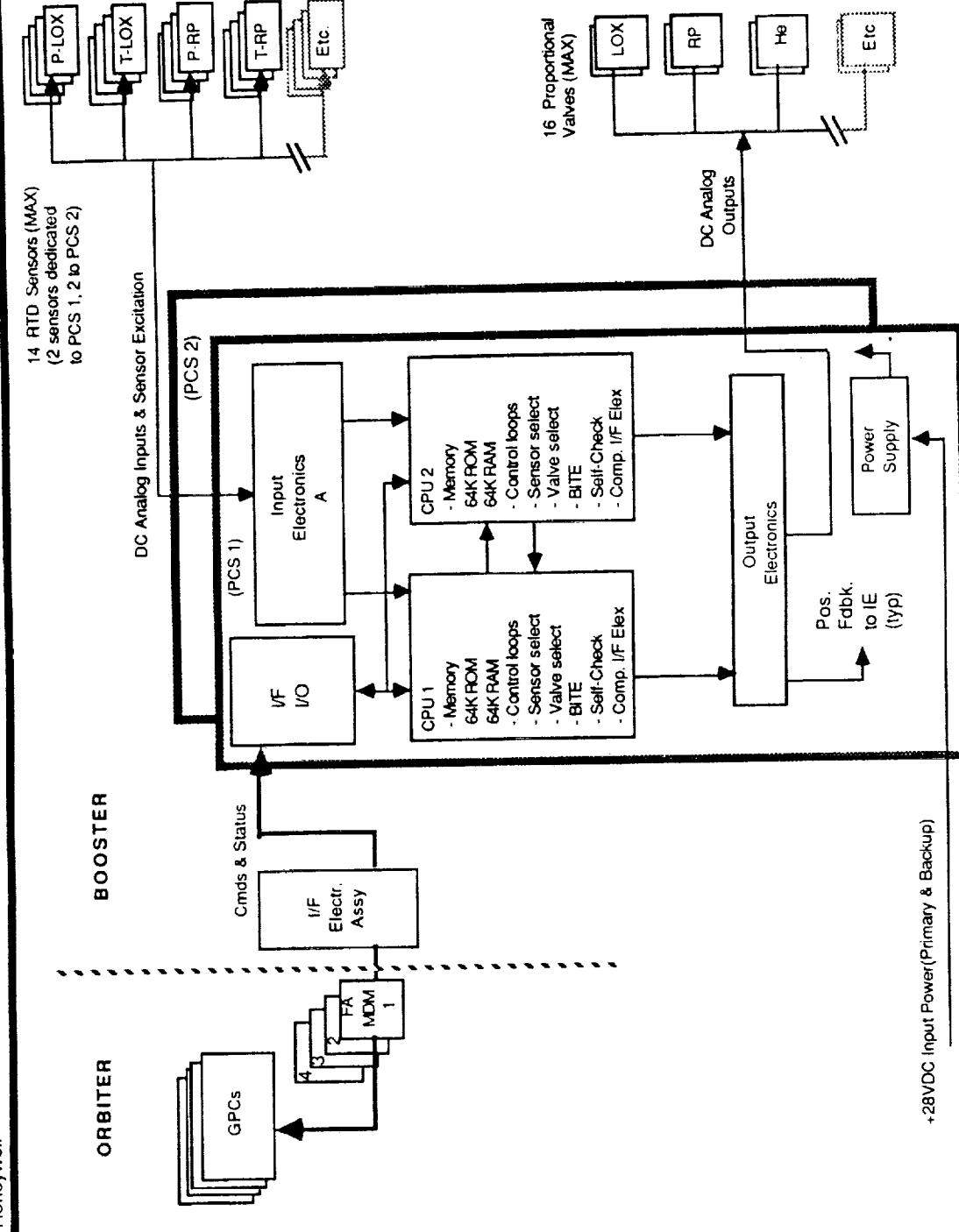
PROPELLANT TANK PRESSURIZATION TECHNOLOGY PROGRAM
ROM

Honeywell

305

Honeywell

PTPTP Flight Pressurization Control System Architecture



PTPTP FLIGHT PRESSURIZATION CONTROL SYSTEM

ROM COST ASSUMPTIONS

GENERAL

1. The PCS will comply with the Separation of Critical Functions requirement of MJ070-0001-1C. (3.4.1.13). Therefore, redundant means of performing critical functions will be physically separated or protected.
2. The PCS is a Critical Function of Category 1. (could result in loss of crew or flight vehicle)
3. The PCS will receive Flight Critical commands from the GPCs. The PCS will also relay its operational status to the GPCs.
4. The PCS will consist of dual redundant LRUs and each LRU will be part of a string. How each string will be configured to the Data Management System will not be determined at this time.
5. Each LRU will consist of self-checking processors, single input electronics, and single output electronics that will give each redundant LRU 100% Self-test. An LRU will initiate a shutdown and switch to a redundant LRU before any out-of tolerance signal is output to any valve actuator.
6. Each redundant LRU will be capable of initiating an "active" shutdown. (Active is defined as alternative shutdown procedures to be performed depending upon elapsed time of the mission).
7. Unless otherwise specified, the PCS will not perform any booster engine control.
8. Smart sensors will not be used. Excitation must be provided to the sensors. Each LRU will control two of the four sensors at each location only. RTD sensors are assumed. Valves and sensors for testing are customer furnished.
9. Valve position feedback will be needed.
10. ROM applies to all three final candidates: Concepts 2, 4A-2, & 4Z (Concept 4Z is worst case)
11. All S/W development 50% as complex as SSMEC. (2 Programs, "C" language assumed)
12. The LRUs will not require AC power
13. A shipset consists of 4 LRUs. (2 LRUs per booster, 2 boosters per flight)
14. This ROM will determine the non-recurring and recurring price for :

Program first flight:	Jan 1996
Begin first booster assembly:	Jan 1995
First assembled & fully qualified flight unit:	Jan 1995
Begin long lead parts procurement:	Jan 1992
Total expendable flights (2 boosters per flight):	12 (48 LRUs) (Recurring prices would differ if > 12 flights))
Flights per year:	See schedule

Learning curve:	90%
Pricing dollars, year:	1987

15. All S/W requirements will be fully defined.
16. A COST reimbursable contract.
17. Class "B" parts are assumed.
18. The recurring price stated is for one shipset (4-LRU's) out of the initial 12 shipsets being produced.

TEST EQUIPMENT

1. Pricing is based upon a long-term production program.
2. 2 separate sets of in-house LRU resident flight S/W. (Flight S/W & CATP)
3. ATE can be scaled down with appropriate adapters and is available for board level testing.
4. No S/W development system is needed. (SSMEC station will be available).
5. Certification test adapter is manual, but could grow to automatic.
6. DS Part II included in Certification estimates.
7. Interface adapters are approximately 40% SSMEC CITA capacity, are design apportioned, and include debug S/W.
8. Certification adapter uses debug S/W and manual measurements.
9. Board test adapters & power supply adapters use ATE station separate S/W.
10. Closed loop simulation is needed for flight S/W development.

FLIGHT PRESSURIZATION CONTROL SYSTEM SCHEDULE & ROM PRICES

